STRATIGRAPHY AND SEDIMENTOLOGY OF THE NILE GROUP (OLIGOCENE) SOUTHWEST NELSON

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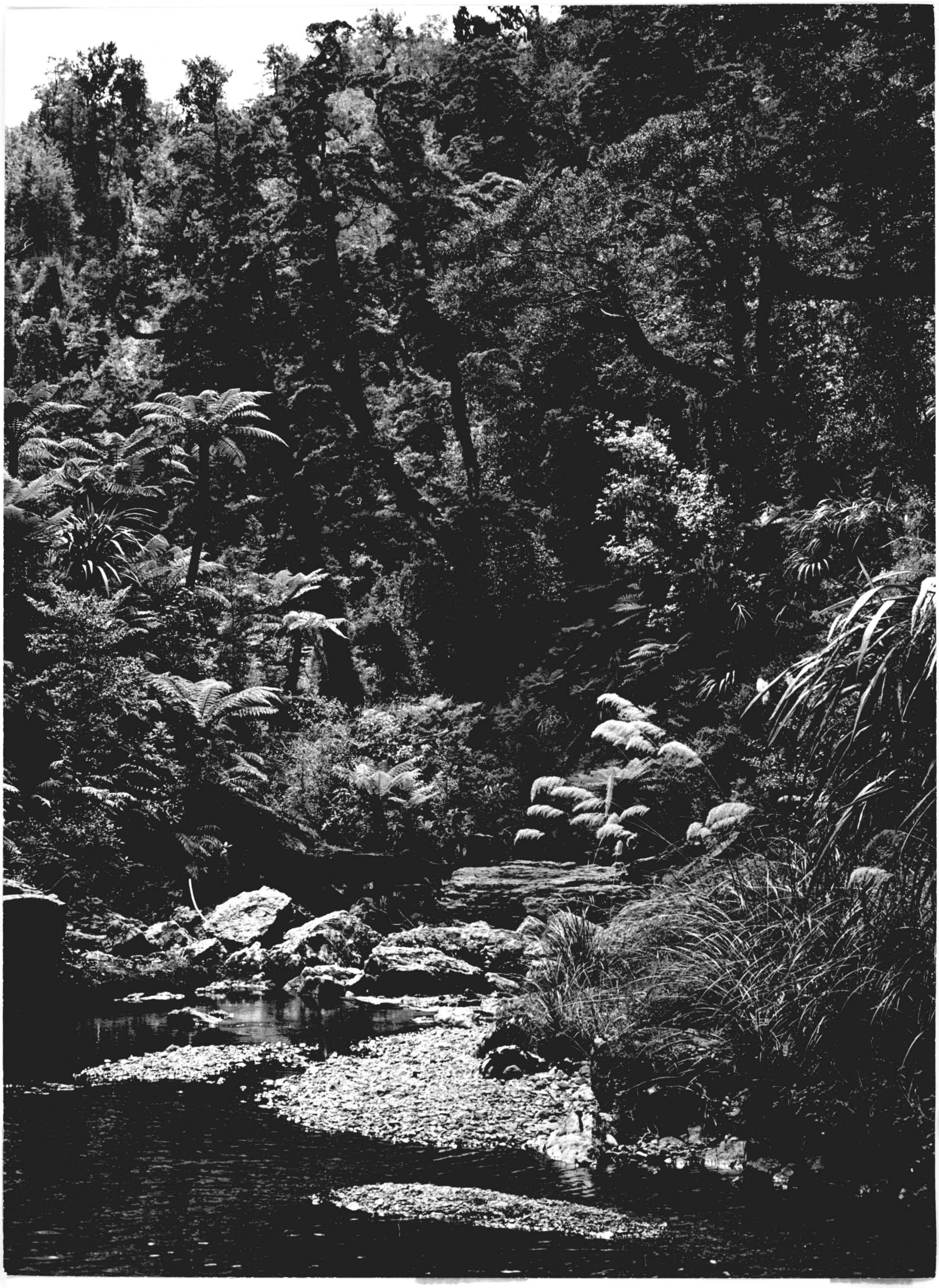
" ... the uncertainty of the climate, for whilst few districts can boast such perfect days when the sun does shine, few become so frequently and gloomily immersed in all-pervading rain."

Morgan & Bartrum, 1915, p. 8.



ABSTRACT

Two new formations comprise the Nile Group; the lower Little Wanganui Formation and the upper Karamea Limestone. The Little Wanganui Formation contains the Kongahu Member (new name), Glasseye Mudstone (new name), and Kohaihai Limestone (new name). The Whaingaroan to late Duntroonian Kongahu Member consists of mass transported fossiliferous sandstones and conglomerates/breccias, which were derived from a landmass situated to the west of Kongahu Point. The member, which is largely confined to the coast between the Mokihinui and Little Wanganui Rivers, nonconformably overlies Paparoa Granite or is interbedded with the Kaiata Mudstone and (or) Glasseye Mudstone. The Whaingaroan-Waitakian Glasseye Mudstone is an open marine calcareous detrital lutite, which is limited to the southern half of the study area. The Kohaihai Limestone is a shallow marine echinoderm biosparite, which conformably overlies the coaly Mawheranui Group in the Karamea region.

The Karamea Limestone consists of the Stony Creek Limestone Member (new name) and the Oparara Member (new name). The Waitakian Stony Creek Limestone Member, a bryozoan biosparite, unconformably overlies the Kohaihai Limestone and the Glasseye Mudstone, or rests on Karamea Granite. The Oparara Member consists of calcareous very fine sandstone or fine-grained bryozoan biosparite; the member conformably overlies the Stony Creek Limestone in the Karamea region, unconformably overlies the Glasseye

Mudstone elsewhere, and is conformably overlain by the Blue Bottom Group.

The distribution of lithologies suggests that two sedimentary regimes operated in the study area during middle Tertiary time. The northern (Karamea) region was the site of a relatively stable, shallow, current swept, slowly subsiding carbonate shelf. The remainder of the study area was occupied by a rapidly subsiding marine basin (Little Wanganui basin), flanked on the west by a small rugged granitic landmass. Tectonic activity along the Paparoa Tectonic Zone during the late Eocene-middle Oligocene created an archipelago of islands with associated NNE trending basins; the most northerly of which constituted the Little Wanganui basin.

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CHAPTER 1

INTRODUCTION

PURPOSE

This thesis records and interprets the sedimentary geology of the Landon and Pareora Series limestones, calcareous mudstones, and fossiliferous sandstones/conglomerates that are exposed in the coastal area between the Kohaihai and Mokihinui Rivers, West Coast, South Island (Fig. 1/1). The depositional history of the rocks, as interpreted from sedimentary structures and textures, vertical and lateral sedimentary facies, fossils, and trace fossils, forms the basis of this study.

GENERAL SETTING

Limits of study area

The coastline from the Mokihinui River to Kohaihai Bluff is the western limit of the study area. The exposures of Landon rocks along the inland edge of the coastal plain from Kohaihai Bluff to Oparara, the Westport-Karamea road, Provincial Highway 67, and the exposure at Limestone Creek (S18/658218)[1] delineate the eastern limit.

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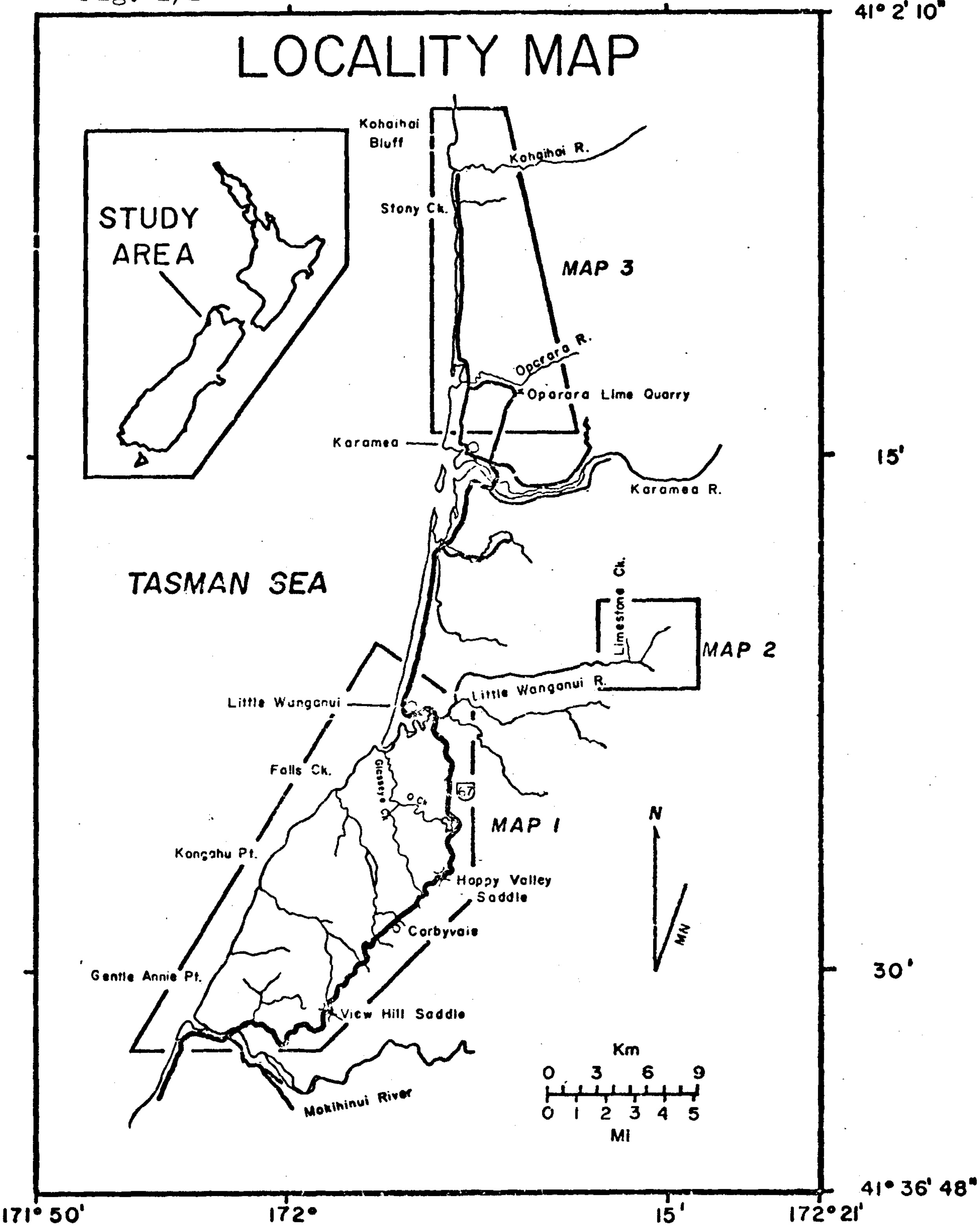
[1]Grid references used in this study come from the NZMS 1 topographic maps for Karamea (2nd edition, 1974) sheet S12, and Little Wanganui (2nd edition, 1973) sheets S17, S18.

Fig. 1/1


LOCALITY MAP
STUDY AREA
Kohaihai Bluff
Kohaihai R.
Stony Ck.
MAP 3
Oparara R.
Oparara Lime Quarry
Karamea
Karamea R.
TASMAN SEA
Limestone Ck.
MAP 2
Little Wanganui R.
Little Wanganui
Falls Ck.
Glasseye Ck.
O Ck.
67
MAP I
Kongahu Pt.
Happy Valley Saddle
Corbyvale
Gentle Annie Pt.
View Hill Saddle
Mokihinui River
N
MN
Km
0 3 6 9
0 1 2 3 4 5
MI
41° 2' 10"
15'
30'
41° 36' 48"
171° 50'
172°
15'
172° 21'

Access

The main exposures of Landon sequences occur at the margins of the Gunner and Stormy Anticlines, in the coastal cliffs between Gentle Annie Point and Little Wanganui Head, and along Highway 67 from the Mokihinui to the Little Wanganui Rivers (Fig. 1/1 and columnar sections in back pocket).

Kohaihai Bluff can be approached in dry weather by fording the Kohaihai River at low tide. However, dangerous breakers prevent access from the south to exposures on the north side of the bluff. A side track, which branches from the Heaphy Track at the top of the first saddle (approximately 1.3 km from the start of the track), allows access to the north side of the bluff.

The most direct way of reaching the Little Wanganui Head section is to wade across the mouth of the river at the sand bar. It is safer and more comfortable to cross Glasseye Creek and follow the south bank of the river.

The section at Falls Creek is generally approached via the coast from Little Wanganui Head, but it can also be reached by following an overgrown pack trail on the west bank of Glasseye Creek and by crossing over the ridge into the Falls Creek catchment.

Kongahu Point is accessible by boat from Mokihinui or the Little Wanganui settlement. Breakers wash against steep cliffs at Otahu Hill, just south of Falls Creek, and prevent access to the section from the north. An

11 km walk along the coast from Gentle Annie Point gives the easiest access to this section. An approach from Highway 67 via Six Mile Creek, through native bush, is possible with sufficient good weather and stamina.

A disused tramway along the top of the terrace provides the easiest access to the northern portion of the Gentle Annie Point outcrop.

Topography

Steep-sided hills (Tertiary sediments), which are generally less than 2000 feet high and are densely clothed in native bush, characterize the topography between the Mokihinui and Little Wanganui Rivers (NZMS 1, Little Wanganui S17, S18, 1973). Slips scar many of the steeper slopes and dam several streams; for example, the large lake at the head of Falls Creek (Fig. 1/1) was dammed as a result of the 1968 earthquake. Precipitous cliffs mark the coastline 0.4 km south of Falls Creek at Otahu Hill. Because of the mild climate and ample rainfall, the subtropical native bush is exceptionally beautiful and luxuriant (and contains liberal quantities of stinging nettle, bush lawyer, supplejack, and hookgrass!).

A low-lying coastal plain, about 1.4 km wide, extends from Little Wanganui to the Oparara River. Much of this land is cattle pasturage or is under cultivation. From the Oparara River to Kohaihai Bluff, the plain narrows and abuts to the east against low hills of Tertiary sediment. These sediments rest on granite, which forms the higher hills and mountains of the inland area.

GEOLOGY

Age

The rocks that were studied are mainly of Landon age (Oligocene epoch, c. 37.6-22.4 myBP--Berggren, 1972). Microfaunal studies, especially those of S. Duff (U. of C., M.Sc. student specializing in paleontology), indicate that rocks of all three Landon stages are present (App. II). The examined rocks include those between the Middle Coal Measures and Southland Series Blue Bottom siltstone.

Lithology

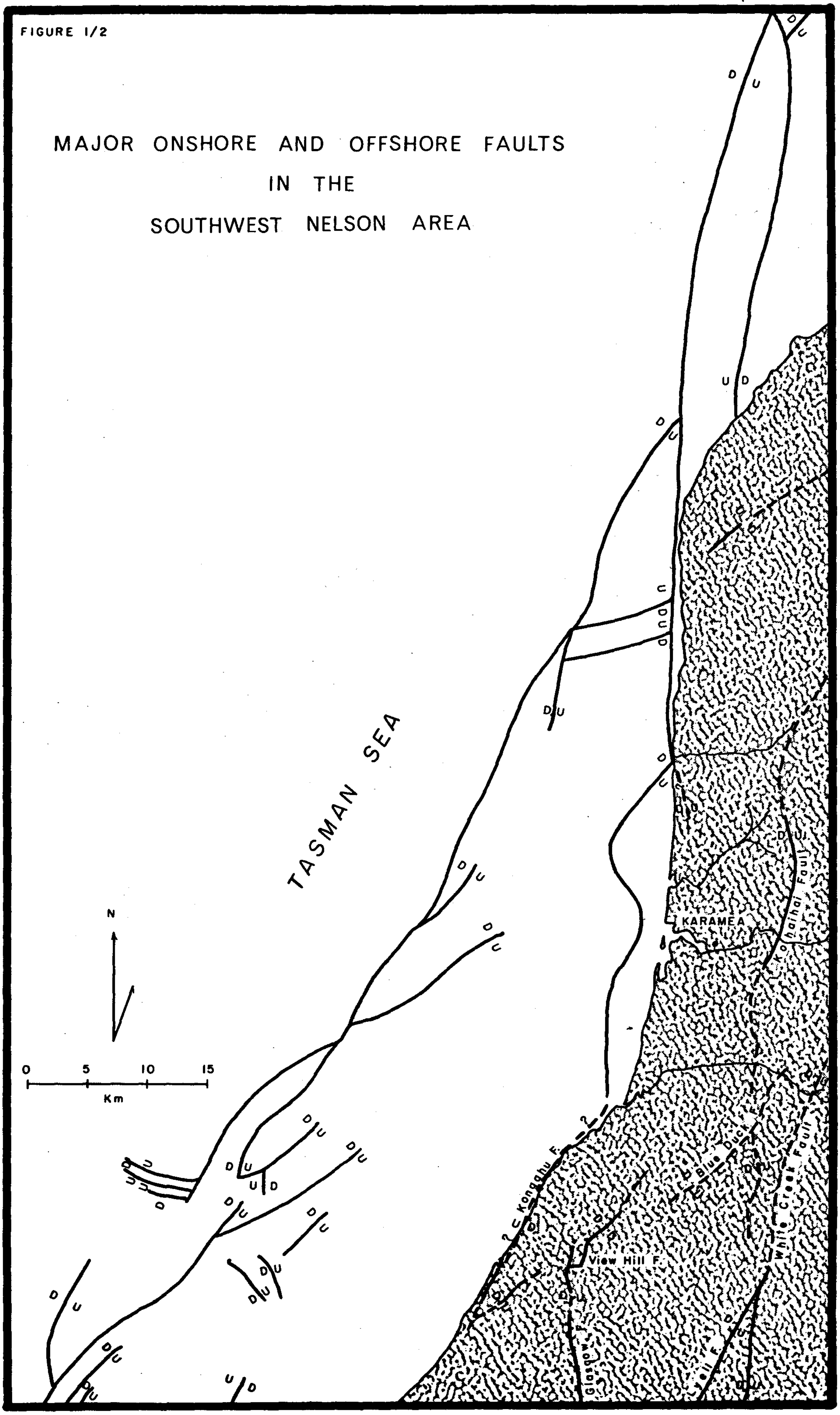
Calcareous detrital mudstone, limestone, and sandstone/conglomerate are the dominant lithologies in the Landon and Pareora Series of the study area. Mudstone dominates the studied sequence south of the Little Wanganui River. The mudstone is typically burrowed, light grey, silty, and calcareous. The rock contains numerous microfossils. Sedimentary structures, other than fine parallel laminations, are scarce. Limestones occur mainly in the Karamea-Kohaihai area and along the coast between the Little Wanganui and Mokihinui Rivers. In the Karamea-Kohaihai area, a slightly sandy bryozoan biosparite dominates. The biosparite grades laterally into a pecten biomicrudite at Kohaihai Bluff. Very sandy, slightly muddy foraminiferal-echinoderm-bryozoan biosparite is interbedded with mudstone along the coast south of Little Wanganui. Sandstone and minor amounts of conglomerate crop out in the lowest part of the Landon sequence in the Karamea-Kohaihai area. Thin- to very thick-bedded sandstones and granitic conglomerates are common along the coast south of Little Wanganui. Some of the coastal conglomerates contain large, angular granite boulders (up to 10 m in diameter). These conglomerates may be classified as sedimentary breccias.

Structure

A series of fault depressions on the western side of several N-NNE trending dextral transcurrent faults preserves folded Tertiary sediments (Grindley, 1961; Geological maps in back pocket). Seismic offshore data (Hematite Petroleum, Ltd., 1975) indicate that a major fault system exists 20-30 km offshore and is roughly parallel to both the present coastline and the major faults (determined from onshore mapping) in the study area (Fig. 1/2 and Geol. maps). Uplift on the Kongahu Fault (present at Kongahu Point) may be responsible for the cliffed shoreline. This fault appears to continue northwards from the mouth of the Little Wanganui River to beyond Kohaihai River. According to Laird (1968), the fault develops into a thrust near the Mokihinui River, where granite from the east has been thrust

FIGURE 1/2

MAJOR ONSHORE AND OFFSHORE FAULTS
IN THE
SOUTHWEST NELSON AREA



westwards onto Tertiary sediments. Laird (op. cit.) postulates that south of Hector the fault is replaced by a westward overfold, which even further south becomes a monocline with a steep western side. This fold-fault zone--termed the Paparoa Tectonic Zone by Laird (op. cit.)--was tectonically active in the Granity district during the upper Eocene (Laird and Hope, 1968). Post-Miocene overfolding, possible thrusting, and normal faulting of Middle Tertiary sediments is probably related to the Kaikoura Orogeny.

More discussions of the structures are found in Webb (1910) and Wellman (unpubl.).

THE GEOLOGICAL MAP

The geological maps (back pocket) incorporate information from a number of sources. The offshore structural data comes from the maps of Hematite Petroleum Ltd. (Press Release 555, 1975). The geology of the area south of the Little Wanganui River is taken from the map that Grindley (1950) compiled for the N. Z. Geological Survey Bulletin (IV), "Tertiary Geology of Sheets S17 and S18" (unpubl.). Grindley (1961) is the source of the geology that is depicted north of the Little Wanganui River. I redrew Grindley's maps substituting lithostratigraphic for chronostratigraphic units and included some structural data of my own.

Middle Tertiary rocks between the Mokihinui and Little Wanganui Rivers generally strike to the N-NE and dip to the east. Gentle folding affects the structure locally. The View Hill Syncline plunges to the southwest. The resistant Oparara Member, which is easily traced in the bush, delineates the syncline. Major faults are present at Kongahu Point and along the highway south of Corbyvale, where the View Hill Fault juxtaposes the light colored Glasseye Mudstone against the dark brown basement rocks. At Gentle Annie Point, the sediments are vertical to slightly overturned in response to late Tertiary folding and major offshore faulting (Map 1).

The Limestone Creek exposures crop out at the nose of the Stormy Anticline. The Stony Creek Limestone (Map 2) clearly outlines this structure.

The geological map depicts the Gunner Anticline as a relatively simple structure (Map 3), but the structure is undoubtedly more complex than shown.

PREVIOUS WORK

Charles Heaphy and Thomas Brunner, surveyors in the employment of the New Zealand Land Co., struggled down the coast from Wanganui Inlet to the Arahura River and made the earliest exploration of the coastal margin of the study area in 1846 (Heaphy, 1847, cited by Morgan and Bartrum, 1915).

The discovery of gold and coal on the West Coast in the late eighteen fifties provided an incentive for the first geological exploration of the area, undertaken by Julius von Haast in 1860 (see J. von Haast, 1861; H. F. Haast, 1948). In August of that year, Von Haast and his small party crossed the Mokihinui River (on a mokihi--a flax stick raft) and began the difficult trek along the coast to Wanganui Inlet. In spite of horrible weather, sandflies, injuries, and a lack of food, Von Haast made a number of very perceptive geological observations. His description of the contact between the granite basement and the Landon sediments at Kongahu Point is especially excellent. He did much of the topographical surveying on the coast from an observation post lashed to the top of the tallest tree on Otahu Hill, about three quarters of a kilometer south of Falls Creek. The quality of the drawings and maps that he produced under such conditions is truly amazing.

In 1874, Alexander McKay made several collections of fossils along the West Coast, including one at Gentle Annie Point. He went northwards along the coast as far as Six Mile Creek and published a brief description of the sediments in 1877.

Very little geological work of any consequence was done in the area between 1874 and 1910, although Hector (1884) and McKay (1895) made occasional visits to the district. This neglect occurred despite the discovery of gold (1870) within the beach sands of the Little Wanganui River and in patches of alluvium along Glasseye Creek. Mining in the district declined sharply after about 1880, but the discovery in Silver Creek of ore containing appreciable amounts of copper, molybdenum, silver, and gold caused a revival in 1906. Robert Johnson eventually traced the ore to the Mt. Radiant area (Webb, 1910). Encouraged by the discovery, the New Zealand Geological Survey sent Ernest Webb in 1908 to investigate the extent of the ore bodies and to produce a general geological description of the area. He published the results of the pioneer investigation in 1910. One of his major contributions was the mapping of a major fault through Kongahu Point.

In 1915, Morgan and Bartrum described the Tertiary sequence at Gentle Annie Point and estimated the throw of Webb's Kongahu Fault at between 1000 and 2000 feet. They asserted that this fault could be traced from Kongahu Point to south of the Mokihinui River as a northerly extension of the Lower Buller Fault, which was mapped along the base of the Paparoa and Papahaua Mountains by McKay in 1892 (cited in Morgan and Bartrum, 1915).

Henderson (1937) described in detail the effects of the 1929 earthquake. In his publication, he gave extensive treatment to a major rotational slump at White Cliffs, 1.2 km north of Kongahu Point. The slump locally elevated the seabed over 100 feet.

No further geological work was undertaken in the area until the late 1940's, when Harold Wellman compiled the data for the New Zealand Geological Survey Bulletin 57 (unpubl.) on Sheets S17, S18 (Little Wanganui). This work and its accompanying map, which was prepared by Grindley, appears in the 1 : 250 000 geological map for Golden Bay (Grindley, 1961). These maps are the basis for the geological maps in the back pocket.

Geological work in the area during the last 25 years has been sporadic. Mining exploration of Mt. Radiant in the early sixties was apparently unsuccessful. Laird (1968) examined the faults near Gentle Annie Point while preparing his paper on the Paparoa Tectonic Zone. G. Neef studied the Southland Series rocks in the Karamea-Little Wanganui area during 1973 and 1974. His report, when published, will no doubt revise much of the mapped structure and upper Tertiary stratigraphy.

METHODS

Field work

Field work was undertaken at irregular intervals from November 1974 to December 1975. The inland road sections (Logs 9 and 10)[1] are general and incorporate data from View Hill (S18/476009), the Corbyvale area (S18/503052), and Happy Valley Saddle (S18/542089).

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[1]All logs are located in back pocket.

Inclement weather at Kongahu Point prevented me from completing a detailed analysis of the sediments, hence the generalized nature of Log 5. I visited Limestone Creek (S18/658218) on the Wangapeka Track, but based much of Log 4 on the work of Wellman (unpubl.), because of the poor outcrop quality.

The best outcrops are on the coast and along the highway. Exposures along the major streams (Glasseye Creek, lower Q Creek, Falls Creek and Three Mile Creek) are largely obscured by dense bush. Direct tape measurements and pace and compass traverses (Lahee, 1961, p. 473) provided the thickness data for log preparation.

Laboratory analyses

Samples were selected both to represent the different lithologies in each section and to determine gross vertical variations through thick or repetitive sequences of similar lithology (e.g., mudstone). The outcrop logs give details of sample locations.

Petrological work on 96 thin sections included qualitative estimates of maximum and modal detrital grain sizes for use in textural analyses (Chap. 5), and semi-quantitative estimates of the amount and type of allochems, detritus, and matrix cement. Point-count data from several of the slides checked the reliability of these estimates (App. I).

Polished slabs and acetate peels were prepared from hand specimens exhibiting particularly interesting textures or fossil content. Peel preparation involved the etching of limestones in 10 % HCl for about 10 seconds. The hydrofluoric acid etching technique of Price (1975) enabled preparation of acetate peels from cherts and siliceous mudstones.

X-ray diffraction analysis of clay minerals followed procedures outlined in Carroll (1970).

This thesis uses the foraminiferal age determinations of H. J. Finlay, which were originally compiled for Dr. Wellman's unpublished bulletin and revised at various times by Dr. Hornibrook and G. H. Scott (in 1968). Mr. S. Duff identified the foraminifera used to date several of the samples.[1] This thesis does not include a detailed fossil-based paleoecological analysis, although much scope for future faunal studies exists.

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[1]References consulted were Hornibrook (1961, 1971), Hornibrook and Brazier (1968), and Jenkins (1971).

CHAPTER 2

PROPOSAL FOR THE DESIGNATION OF FORMAL STRATIGRAPHIC UNITS

Nathan (1973) suggested a comprehensive lithostratigraphic classification for the Cenozoic rocks of north Westland and southwest Nelson. His major units, the groups, can be employed between the Kohaihai and Mokihinui Rivers, but local formations are necessary, with one exception (see Tables 2/1 and 2/2).

MAWHERANUI GROUP

Non-marine coal measures crop out near Corbyvale on the western side of the Gunner Anticline. These sediments, which were termed the Middle Coal Measures by previous writers, correlate with the coal measures in the Mawheranui Group of Nathan (1973) and possibly with the Motupipi Coal Measures of the Westhaven Group (Grindley, 1971). No attempt has been made to subdivide the unit that is referred to in this report as "undifferentiated Mawheranui Group".

The best exposure of these sediments is near Stony Creek (Log 2), where 53 m of the unit rest nonconformably on leached Karamea Granite. The dominant lithology is friable, poorly sorted, muddy very fine to medium sandstone, which is locally pyritic and contains numerous coaly laminations. No fossiliferous samples were

TABLE 2/1 Lithostratigraphic Units Recognized in Study Area

Blue Bottom Group	undifferentiated Blue Bottom Group			
Nile Group	Karamea Limestone	Stony Creek Limestone Member	Oparara Member Member	
	Little Wanganui Formation	Kohaihai Limestone Member	Glasseye Mudstone Member	Kongahu Member
Rapahoe Group	Kaiata Formation			
Mawheranui Group	undifferentiated Mawheranui Group			

TABLE 2/2 TABLE OF GEOLOGICAL FORMATIONS*

Age	Series	Mc Kay, 1895	Park, 1910	Webb, 1910	Morgan, 1911	Marshall, 1912	Morgan & Bartrum, 1915	Nathan, 1973	This report
Miocene	SOUTHLAND PAREORA			Upper	Blue Bottom		Upper	Blue Bottom Group	Undifferentiated Blue Bottom Group
Regional Unconformity		Lower Miocene	Oamaru Series						
Oligocene	LANDON: Waitakian	Cretaceo-Tertiary and the Cretaceous Upper	Karamea System	Kongahu Series	Greymouth Series	Wanganui System	Oamaru Series		Nile Group: Karamea Limestone 2 members
	LANDON: Duntroonian	Middle		Lower	Cobden Ls., Port Elizabeth Beds		Middle	Nile Group	Nile Group: Little Wanganui Formation 3 members
	LANDON: Whaingaroan		Waimangaroa Series			Oamaru System			
Eocene	ARNOLD	Lower					Lower	Kaiata Formation (Various other groups)	Kaiata Formation; undifferentiated Mawheranui Group

*Modified from Morgan and Bartrum, 1915

collected, but on stratigraphic grounds the sediment is probably Bortonian to Whaingaroan.

RAPAHOE GROUP

Kaiata Formation

The Kaiata Mudstone Member is probably the sole representative of the Kaiata Formation (Nathan, in press a; in press b) in the study area. The dominant lithology is a dark brown, poorly indurated, micaceous, slightly calcareous mudstone, which grades upwards into a dark grey-brown, calcareous fine sandy mudstone. The unit covers the southern third of the study area. It is approximately 100 m thick near the Mokihinui River, and possibly thickens toward Corbyvale.

The Kaiata Mudstone interfingers with the Kongahu Member of the Little Wanganui Formation north of Corbyvale. It probably conformably overlies the undifferentiated Mawheranui Group at Corbyvale and near the Mokihinui River. The contact with the overlying Nile Group sediments south of View Hill on Highway 67 is covered and faulted.

The exact stratigraphic relationships between the Kaiata Mudstone and the surrounding units remain a mystery. The contact with the underlying Mawheranui Group coal measures is of particular interest. These units may be partially time-equivalent and may have gradational lateral contacts. A similar situation may exist between the overlying Little Wanganui Formation (Glasseye Mudstone

Member) and the Kaiata Mudstone. Clarification of these stratigraphic details would greatly aid paleoenvironmental reconstructions.

Foraminifera are the dominant fossils in the Kaiata Mudstone. The presence of Globigerina angiporoides and G. ampliapertura dates the upper portion of the unit north of Corbyvale as lower Whaingaroan (N. de B. Hornibrook, pers. comm.). The base of the unit may be Kaiatan.

NILE GROUP

The Nile Group of Nathan (1973) encompasses the widespread Oligocene calcareous rocks of Buller and north Westland. This report tentatively extends the Nile Group into southwest Nelson on stratigraphic and lithologic grounds. The following formations comprise the Nile Group in the study area:

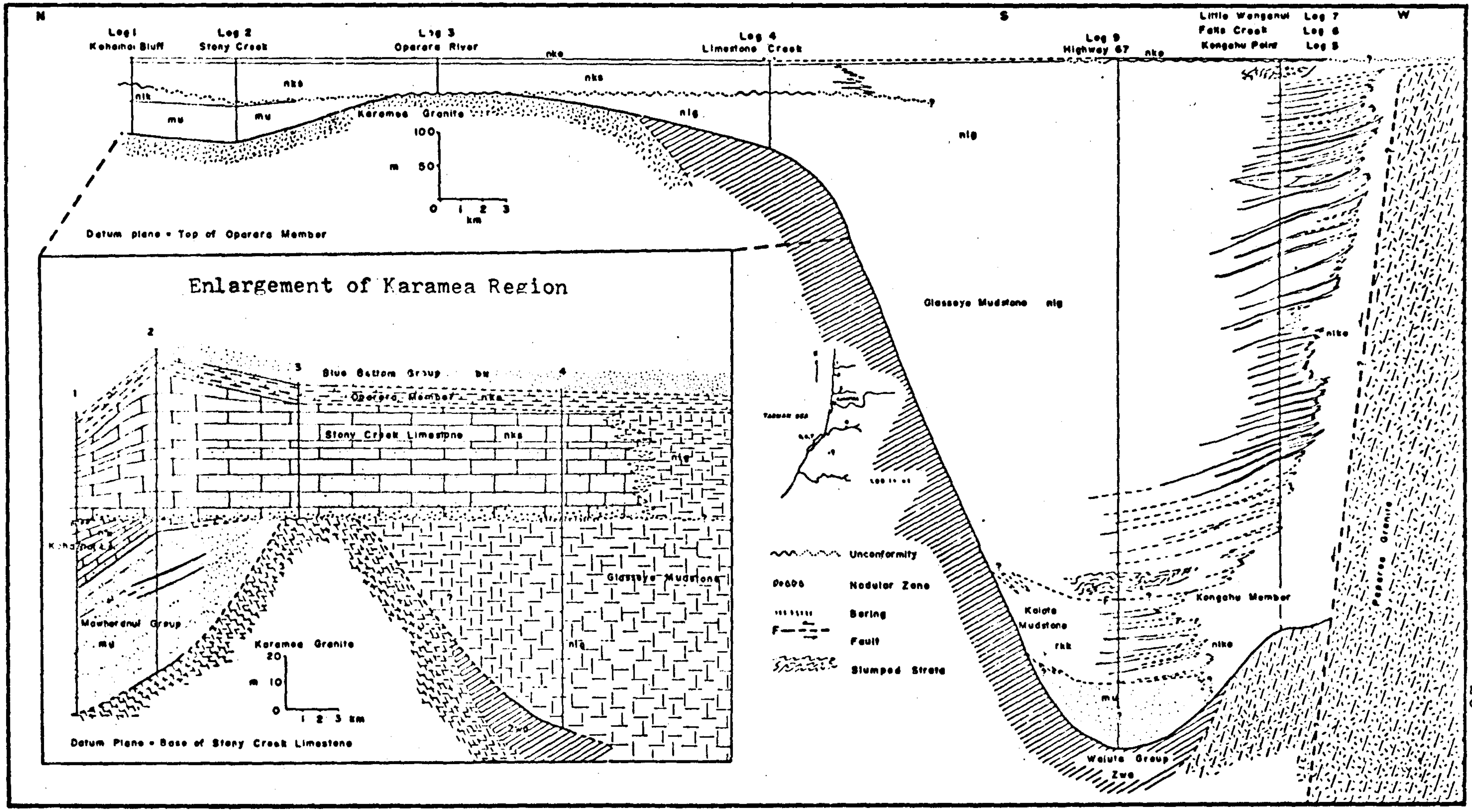
Little Wanganui Formation (new formation) (3 members)

Lithologies include: sandy limestone; calcareous mudstone; and redeposited sandstone, sandy limestone, and fossiliferous granite breccia. The formation includes the majority of the studied rocks.

Karamea Limestone (new formation) (2 members)

Lithologies include: flaggy, bryozoan limestone; bryozoa Amphistegina limestone; and fossiliferous very fine sandstone. (Fig. 2/1)

Fig. 2/1 Semi-Schematic Correlation Diagram of the Nile Group



Little Wanganui Formation

Nomenclature

The Little Wanganui Formation--named after the Little Wanganui River (S18)--includes three lithologically distinct units: the Glasseye Mudstone; the Kongahu Member; and the Kohaihai Limestone. In the Karamea area, the formation consists solely of the Kohaihai Limestone (the calcareous sediments that lie between the Mawheranui Group coal measures and the flaggy, bryozoan Stony Creek Limestone member of the Karamea Limestone). In the southern half of the study area, the formation includes the largely calcareous sediments (Glasseye Mudstone, Kongahu Member) that overlie the Kaiata Formation, Mawheranui Group coal measures or Paparoa Granite (depending on locality), and which underlie either the Oligocene regional unconformity or the Oparara Member of the Karamea Limestone. The stratigraphic position, flysch-like occurrence, and lithologically distinct nature of the Kongahu Member and Glasseye Mudstone justify their inclusion in the Little Wanganui Formation. The stratigraphic position and partial time-equivalence of the Kohaihai Limestone to the Kongahu Member and Glasseye Mudstone justify its inclusion in the Little Wanganui Formation.

The Glasseye Mudstone is named after Glasseye Creek (S18). The Kongahu Member is named after Kongahu Point (S18/454100), where the base of the unit is exposed. Kohaihai Bluff (S12/551522) is the source of the name for the Kohaihai Limestone.

The type section for the Little Wanganui Formation is composite, being composed of the type sections for the individual members. Kohaihai Bluff (S12/551522; Log 1) is the type section for the Kohaihai Limestone. The type area for the Glasseye Mudstone is a composite section along Highway 67 from near Happy Valley Saddle (S18/553095) to Corbyvale Valley[1] (Log 9). The coastal cliffs from Kongahu Point to the mouth of Glasseye Creek on the Little Wanganui River form the composite type section for the Kongahu Member (Logs 5-7).

Distribution and Thickness

The Little Wanganui Formation occurs throughout the study area, although the members have restricted ranges. The Kohaihai Limestone, the only member present in the northern third of the study area, is 43 m thick at the type locality. The member thickens to the north and pinches out to the south near the mouth of Oparara River. This pinching is attributed to local Duntroonian-Waitakian uplift and erosion. The formation thickens rapidly south of the Little Wanganui River; it is 800 m thick along Highway 67 and about 890 m thick along the coast. The Glasseye Mudstone, which is restricted to the southern half of the study area, is about 800 m thick in the type area, but thins to the north, west and probably to the east and south. The Kongahu Member is largely restricted to the coast between the Little

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[1]Corbyvale Valley is not a recognized Geographic Board name.

Wanganui and Mokihinui rivers. The unit is about 200 m thick in the type area but thins very rapidly to the east; its total thickness along Highway 67 is about 20 m.

Lithology

Kohaihai Limestone. The lower quarter of the unit is a light reddish-brown, poorly indurated, slightly calcareous, fine pebbly medium sandstone. This lithology grades upwards into light brown, poorly indurated, slightly glauconitic, coarse sandy foraminiferal echinoderm biosparite. The upper 2m of the member at the type locality is a nodular, light greyish-yellow-brown, fine sandy bryozoan foraminiferal echinoderm biomicrite. Sedimentary structures are rare except for discontinuous, very thin coaly laminations present in the lower 12 m and very obscure current laminations in the upper part of the sequence at Kohaihai Bluff. Macrofossils include brachiopods, bivalves, echinoderm and bryozoan fragments, and solitary corals. Foraminifera are abundant. Burrowing is widespread, particularly in the upper 5 m, but the traces are not well preserved.

Glasseye Mudstone. The unit is typically medium grey to light brown (weathers light yellowish-brown to very light grey), moderately indurated, very calcareous, silty mudstone with softer, more muddy layers. The mudstone is generally bioturbate, but faint light and dark laminae are occasionally present. The laminae are often sandy and may contain appreciable amounts of finely comminuted carbonaceous material. Macrofossils are rare, but leaf imprints, echinoderm plates and spines, bivalves, and very rare fish and cetacean bones are occasionally present. Common microfossils include foraminifera and sponge spicules. Planolites(?) and Zoophycus are the most abundant trace fossils. Spectacular slump horizons are visible on the highway near Corbyvale (S18/531076) and View Hill Saddle (S18/476013).

Kongahu Member. The unit consists of redeposited and mass-emplaced sediments ranging from non-calcareous granite breccia near the base of the sequence to muddy, coarse sandy, arkosic, bryozoan foraminiferal biosparite near the top. The commonest lithology is medium grey-brown well indurated, fine pebbly, very coarse sandy, arkosic, bryozoan-foraminiferal biosparite. The beds vary in thickness from a few millimeters to over five meters. Many of the beds are lenticular and most exhibit sharp erosional basal contacts and sharp, usually flat, tops. Normal grading, horizontal laminae, load casts, and groove casts are the most common sedimentary structures. Sorting is generally very poor; large granite boulders commonly rest in a muddy, very coarse sandy matrix. Macrofossils, including bryozoa, bivalves, echinoderm and red algal fragments, are plentiful. The large benthonic foraminifera Amphistegina is the dominant microfossil. Exichnial and hypichnial Arthrophycus-like burrow casts are abundant.

A very thin- to thin-bedded red algal foraminiferal biosparite interfingers with Kaiata Mudstone near Corbyvale at S18/531073. The lenticular limestone beds have sharp erosive bases and flat tops. Grading is very common and many of the beds contain faint horizontal laminations. The lenticularity of the beds, the erosive basal contacts, the sedimentary structures, and the presence of a displaced fossil assemblage justify the inclusion of this limestone within the Kongahu Member.

Stratigraphic Relations

The base of the formation in the Karamea area coincides with that of the Kohaihai Limestone, which is defined as the lowest calcareous sediment above the undifferentiated Mawheranui Group. In the southern half of the study area, the formation rests nonconformably on pre-Tertiary igneous and metamorphic rocks (Logs 4 and 5), or interfingers with the Kaiata Formation (see above).

The Kohaihai Limestone conformably overlies the undifferentiated Mawheranui Group and may interfinger with the Glasseye Mudstone east of the study area. The Glasseye Mudstone interfingers with the Kongahu Member and may conformably overlie the Kaiata Formation, although the contact is faulted. The Glasseye Mudstone probably nonconformably overlies schistose greywacke at Limestone Creek (Log 4). The Kongahu Member nonconformably overlies the Paparoa Granite at Kongahu Point and Gentle Annie Point (Logs 5 and 8); elsewhere, the member interfingers with the Glasseye Mudstone and the Kaiata Mudstone (Kaiata Formation). The Karamea Limestone unconformably overlies the Little Wanganui Formation throughout the study area.

The Little Wanganui Formation is roughly equivalent to the lower Kongahu Formation of Webb (1910, Table 2/2).

The Kohaihai Limestone may be equivalent to the lower part of the Takaka Limestone, Westhaven Group (Grindley, 1971), or the Abel Head Formation, Westhaven Group (Bishop, 1971). Unequivocal correlation of the Kohaihai Limestone with the above formations must await publication of their formal descriptions.

The Glasseye Mudstone is lithologically similar to several Oligocene muddy limestones and mudstones in the Buller-Nelson area; it may be partly or wholly equivalent to the Cobden Limestone (Greymouth area), Tiropahi Limestone (Charleston-Punakaiki area; Nathan, in press a; Laird, in prep.), and the New Creek Formation of the Inangahua area (Nathan, in press b).

The Kongahu Member is partly correlative with the Lower Kongahu Formation (Webb, 1910).

Age

The formation is dated as Whaingaroan to Duntroonian (possibly lower Waitakian) at Kohaihai Bluff. Elsewhere, the formation is lower Whaingaroan to Waitakian.

Karamea Limestone

Nomenclature

The Karamea Limestone is named after the township of Karamea. It unconformably overlies the Little Wanganui Formation and is conformably overlain by the undifferentiated Blue Bottom Group. The formation includes two lithologically distinct units: a lower Stony Creek Limestone and an upper Oparara Member. The Stony Creek Limestone is named after Stony Creek (S12) near the type section. The Oparara Member is named after the Oparara River (S12).

The type section of the Karamea Limestone is composite, and consists of the type sections of the two members. The type section of the Stony Creek Limestone is an unnamed creek 200 m north of Stony Creek at S12/562472 (Log 2). A limestone quarry on the Oparara River at S12/593378 (Log 3), 1.2 km east of the small township of Oparara, is the type section for the Oparara Member.

Distribution and thickness

The formation is present in the northern two-thirds of the study area. It is about 65 m thick in the Karamea region, but thins rapidly to the south. Sediments possibly correlative with the Karamea Limestone are present in the stratigraphic columns of Wellman, et al. (1973). The sections of Wellman, et al. suggest that the formation thickens to the north, east and southeast of the study area.

The Stony Creek Limestone member crops out in the study area along the western margin of the Gunner Anticline, and at the nose of the Stormy Anticline (Geol. map). The unit probably extends north beyond the Heaphy Syncline and as far east as the upper Karamea River. The southern limit of the member is near Limestone Creek (Log 4). At the type locality, the Stony Creek Limestone is 58 m thick; it thins to the north and south and thickens slightly to the east and southeast.

The Oparara Member occurs throughout the study area as far south as Happy Valley Saddle. The unit is 7 m thick at the type locality, thinning to the south, but probably thickening to the north of the study area.

Lithology

The formation consists of a lower bryozoan limestone (Stony Creek Limestone) and (or) an upper unit of variable lithology (Oparara Member). The Oparara Member and Stony Creek Limestone belong in the same formation, because they have similar allochem assemblages and are in conformable contact in the Karamea area.

At the type locality, the Stony Creek Limestone is a hard, very light yellowish-brown, flaggy, bryozoan biosparite. Subrounded granite and quartz pebbles and coarse granitic sand are common near the base of the unit and on the wavy and irregular bedding planes. Bedding is very thin to very thick; it appears to thicken towards the top. No internal sedimentary structures are apparent. Fragmented bryozoan colonies constitute a major portion of the Limestone. Echinoderm and red algal fragments, brachiopods, bivalves, and benthonic foraminifera are also abundant, particularly near the base. The upper portion of the limestone is almost pure bryozoan biosparite, and contains many hemi-subspherical bryozoan colonies, which impart a pseudo-pisolitic appearance to weathered portions of the limestone. At Limestone Creek (S18/656218) the lithology is similar to that of the type section, but the pyrite-impregnated bryozoan fragments are much smaller. At Kohaihai Bluff, a basal bivalve biomicrudite grades upwards into an echinoderm bryozoan bivalve-fragment biomicrite. This sediment occupies a similar stratigraphic position to the Stony Creek Limestone, and I regard it as a facies variation of the Stony Creek Limestone.

At the type section, the Oparara Member is a medium yellow-brown, moderately indurated, fine pebbly to fine sandy, slightly glauconitic, fine-grained echinoderm bryozoan biosparite. The limestone is massive, thick-bedded, and contains many indistinct Planolites(?) burrow traces. Bryozoan and echinoderm fragments are the dominant macrofossils, although some whole pectens and brachiopods are present. Amphistegina is plentiful. Algal and fungal borings penetrate many of the allochem fragments.

The member contains more detrital material north of the type section and gradually becomes a poorly indurated, fossiliferous, very fine sandstone. In the Limestone Creek area (S18/218656) to the south, the member is finer grained and more muddy than at the type section. It is a light brown, well indurated, muddy, very fine sandy, bryozoan echinoderm foraminiferal biomicrite. The muddy limestone contains numerous Planolites(?) traces and scattered irregular chalcedony nodules. South-southwest of Limestone Creek the unit becomes less muddy and more calcareous. A medium brownish-green, well indurated, very thick-bedded, massive, medium pebbly to very coarse sandy, brachiopod and bivalve fragment foraminiferal bryozoan biosparite (basal part) grading upwards into very fine pebbly echinoderm bryozoan foraminiferal biosparite crops out on Highway 67 near Happy Velley Saddle (Log 9). This limestone grades laterally into an Amphistegina bryozoan biosparite at Glasseye Creek (Log 7).

Stratigraphic relations

The base of the Karamea Formation in the Karamea region corresponds with the first appearances of the flaggy Stony Creek Limestone. This limestone rests unconformably on either older Tertiary sediments or Karamea Granite, although it may interfinger with the Glasseye Mudstone (Geol. map). Limestone of the Oparara Member marks the base of the Karamea Formation where the Stony Creek Limestone is absent; it unconformably overlies the Glasseye Mudstone (Fig. 2/1); elsewhere, the Oparara Member conformably overlies the Stony Creek Limestone.

The unconformity at the base of the formation is marked by a nodular zone at Kohaihai Bluff and by pebble-filled borings in Glasseye Mudstone at Limestone Creek. The Stony Creek Limestone nonconformably overlies the Karamea Granite at the Oparara Quarry. The unconformity resulted from uplift and erosion or non deposition in Duntroonian to early Waitakian time.[1]

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[1]Wellman (unpubl.) noted that the main area of uplift was restricted to a narrow band from 15 Mile Creek in the Aorere Valley (S8), to the Oparara Gorge and south to the Cuckoo River on the western side of the Huia-Kakapo Syncline. Evidence of very minor uplift or non-deposition is widespread over a larger area and supports Wellman's hypothesis that much of the erosion was marine.

Another unconformity lies between the Oparara Member and the Glasseye Mudstone. It is visible at Glasseye Creek and near Happy Valley Saddle and is probably part of the regional unconformity that affected much of the southwest Nelson and Buller region in Waitakian-Altonian time. No evidence of this break in sedimentation is visible north of the Little Wanganui River. The contact between the Glasseye Mudstone and the Oparara Member at Happy Valley Saddle and Glasseye Creek is wavy with a relief of about 0.1 m.

Nathan (1973) used the regional unconformity at Happy Valley Saddle to separate the Nile and Blue Bottom Groups. He therefore included the Oparara Member limestone at Happy Valley Saddle and Glasseye Creek in the Blue Bottom Group. On the other hand, this report places the Oparara Member in the Nile Group primarily because the regional unconformity is not evident in the northern half of the study area, where the Oparara Member conformably overlies the Stony Creek Limestone. Furthermore, the distinctive and widespread Blue Bottom sandstone unequivocally marks the base of the Blue Bottom Group.

The Stony Creek Limestone may be equivalent to the upper part of the Takaka Limestone (Westhaven Group), a bryozoan limestone mapped in northwest Nelson by Grindley (1971). The Takaka Limestone has not been formally described, therefore correlation of the Stony Creek Limestone with it is uncertain. The Kaipuke Siltstone (Westhaven Group) (Bishop, 1968) may be the Oparara Member correlative.

Age

The shell-bearing facies of the Stony Creek Limestone at Kohaihai Bluff yields large quantities of macrofossils, including Athlopecten athleta, which are dated as Waitakian (S12/f503). This age presumably holds for the entire unit. No dates are available from the type locality of the Oparara Member; however, the lower portion of the unit near Stony Creek (Log 2) contains Euuvigerina miozea and Notorotalia spinosa (App. II) giving a Pareora age. The member is Altonian at Happy Valley Saddle (S18/f514) and Otaian to Altonian at the mouth of Glasseye Creek (S18/f599). From the above dates the Karamea Limestone is Duntroonian-Waitakian to undifferentiated Pareora in the Karamea region, and Otaian to Altonian in the south.

BLUE BOTTOM GROUP

Bluish-green, calcareous, slightly glauconitic, muddy, very fine sandstone correlative with the Blue Bottom Group of Nathan (1973) conformably overlies the Karamea Limestone (Nile Group) throughout the study area. This report does not subdivide the Blue Bottom sediments and it refers to them as undifferentiated Blue Bottom Group.

CHAPTER 3

GENERAL SUMMARY OF STRATIGRAPHIC SECTIONS

KOHAIHAI BLUFF LOG 1

Kohaihai Bluff, the most northerly outcrop that was examined, contains a transgressive middle Tertiary sequence. Karamea Granite crops out on the beach immediately north of the bluff. The log for Kohaihai Bluff in Wellman, et al. (1973) shows the upper portion of the granite to be leached, but the contact with the undifferentiated Mawheranui Group is now covered. The undifferentiated Mawheranui Group sediments are about 48 m thick and consist of a friable, poorly sorted, pyritic, micaceous, fine pebbly medium sandstone in a fine white clayey matrix. Sand grains are very angular to subrounded. Very thin carbonaceous laminae are abundant. The Kohaihai Limestone, 26 m thick, conformably overlies the undifferentiated Mawheranui Group.

The basal Kohaihai Limestone is massively bedded, but scarce, thin, discontinuous laminae of carbonaceous material are present in the lower 6 m. The lower 12 m consist of pale yellow, friable, poorly sorted, slightly muddy sandstone: subfeldsarenite. Detrital grains are very angular to subangular. The pale yellow sandstone grades upwards into 2.5 m of light reddish-brown, poorly indurated, moderately sorted, calcareous, coarse sandstone: granite subfeldsarenite. Fossils include poorly preserved pectens, clams, oysters, gastropods, and solitary corals.

A sharp wavy contact, coinciding with the approximate position of the Whaingaroan-Duntroonian boundary, separates the sandstone of the lower Kohaihai Limestone from the upper limestone portion of that member. The limestone is a pale greenish-brown, poorly indurated, moderately well sorted, glauconitic, arenaceous biosparite containing abundant foraminifera and echinoderm and mollusc fragments. Bedding is massive, but discontinuous lenses of shell fragments and very fine quartz pebbles commonly occur in the glauconitic lower half of the limestone.

A 2 m thick nodular horizon at the top of the Kohaihai Limestone marks a local unconformity of late Duntroonian-early Waitakian age. The nodules are well indurated, fine sandy echinoderm-bryozoan biomicrite with many patches of recrystallized micrite. The internodular areas are less well indurated, slightly arenaceous, echinoderm-bryozoan biomicrite. Remnants of very poorly preserved burrows are visible on sawn slabs and on some freshly broken surfaces of the nodular zone.

The nodular horizon is sharply overlain by the Stony Creek Limestone. The Stony Creek Limestone (31 m thick) is extremely fossiliferous, particularly in the lower half. Pectens and Venus-like bivalves are very abundant and several thin beds are nearly monospecific. The limestone is pale greenish-yellow to pale green, very well indurated, bryozoan mollusc fragment biomicrudite. Wavy, very thin to medium bedding is a prominant feature of the limestone. Subangular to rounded, fine pebble- to fine sand-size detrital grains are concentrated on the bedding surfaces.

The Stony Creek Limestone becomes finer grained in its upper portion and is overlain by very calcareous fine sandstone--a facies of the Oparara Member. The contact is covered. Poorly exposed undifferentiated Blue Bottom Group sediments overlie the Oparara Member.

STONY CREEK LOG 2

Outcrops 200 m north of Stony Creek and 4.5 km south of Kohaihai Bluff, reveal a well exposed middle Tertiary sequence resting on weathered Karamea Granite. About 53 m of undifferentiated Mawheranui Group sediments, the lower two-thirds of which are poorly exposed, leach and overlie the upper 1 m of granite. The dominant lithology is a medium brownish-grey, friable, muddy very fine sandstone with abundant thin discontinuous laminae of carbonaceous matter. Occasional bands of angular to subangular fine granite pebbles are associated with discontinuous coaly layers. Five meters of poorly indurated, carbonaceous, muddy very fine sandstone separate two coal seams. The lower seam, 0.6 m thick, overlies a small channel fill. The larger upper seam, about 2.5 m thick, underlies several meters of pyritic, friable very coarse to fine sandstone. One possible root trace is present in a thin coaly lamination about 1 m below the lower coal seam.

The Kohaihai Limestone conformably overlies the Mawheranui Group. The exact position of the base of the Kohaihai Limestone is not exposed, but it is shown on Log 2 as the lowest calcite-cemented sediment.

The basal Kohaihai Limestone is medium reddish-brown, poorly sorted, slightly calcareous, very coarse pebbly to very coarse sandstone: subfeldsarenite-lithic feldsarenite. This sediment grades vertically into a poorly sorted, subangular, fine sandy, glauconitic echinoderm biomicrite. Poorly preserved fossils are common, including pectens, brachiopods (<u>Liothyrella</u> sp.) and cidaroid echinoderm spines. Bedding is massive and the sediment is probably bioturbate, although no discrete burrows are present.

The upper Kohaihai Limestone is a burrowed, light yellow-brown, poorly indurated, slightly very fine sandy, glauconitic echinoderm-foraminiferal biosparite of early to middle Duntroonian age (App. II). This lithology persists for 1.5 m and grades into a moderately indurated, moderately sorted, silty foraminiferal-bryozoan biosparite. This sediment contains abundant tests of the warm water benthonic foraminifera <u>Amphistegina</u> sp.

The Waitakian Stony Creek Limestone sharply overlies the Kohaihai Limestone. The Stony Creek Limestone is 58 m thick and consists of light greyish-brown to yellowish-white, well indurated, fine pebbly bryozoan biosparite. The lower 3-4 m of the Stony Creek Limestone contain numerous rounded fine pebbles of quartz and microcline. Bedding is wavy and thin to very thin near the base of the lithology, but thickens near the top. Total detrital content decreases upwards in the limestone, although fine to coarse sand grains are commonly encountered along the bedding surfaces. Bryozoa, which frequently exhibit a hemi-subspherical growth form, are the dominant fossils. Bryozoa increase in abundance near the top of the Stony Creek Limestone. The subspherical bryozoan colonies impart an almost pisolitic appearance to weathered portions of this limestone.

The contact between the Stony Creek Limestone and the overlying Oparara Member is covered. A pale greyish-green, massively bedded, poorly indurated, calcareous, glauconitic, very fine sandstone of probably Pareora age represents the Oparara Member at Stony Creek (App. II). Iron oxides outline numerous burrows on the pale yellow weathered surfaces of the member. Foraminifera, echinoderm fragments, and pectens are the dominant fossils.

QUARRY NEAR MOUTH OF OPARARA RIVER LOG 3

A 45 m thick section of Stony Creek Limestone is well exposed in a quarry near the mouth of the Oparara River, 9.3 km south-southeast of the Stony Creek area (Log 2). The Waitakian Stony Creek Limestone apparently rests on unweathered Karamea granite; thick bush obscures the 5 m of section between the lowest outcrop of Stony Creek Limestone and the uppermost outcrop of granite. It is assumed that undifferentiated Mawheranui Group and Kohaihai Limestone are absent. The Stony Creek Limestone is a pale yellowish-brown, well indurated echinoderm bryozoan biosparite. It exhibits the thin to very thin, wavy bedding that is characteristic of the Member in the Karamea area. Fine pebbles and coarse sand are common in the lower 2 m of the limestone. The total detrital content decreases upwards through the limestone, but increases in the overlying Oparara Member of Pareora age. Muddy, fine to coarse sand is concentrated along the bedding surfaces of the limestone. Bryozoa are the dominant fossils throughout and are especially abundant in the upper 10 m, where subspherical colonies, 10-50 mm in diameter, abound. Poorly preserved pectens and brachiopods are scattered throughout the limestone. Liothyrellid brachiopods, including many juveniles, are common near the base of the limestone.

A thick-bedded, medium yellow-brown, moderately indurated, fine sandy, slightly glauconitic, fine-grained echinoderm bryozoan biosparite (Oparara Member) of probable Pareora age conformably overlies the Stony Creek Limestone. The Oparara Member does not contain large bryozoan colonies, although its overall allochem composition is similar to that of the underlying Stony Creek Limestone. The fine-grained nature of the sediment may reflect intensive reworking by organisms, although only very obscure burrow traces are in evidence.

Undifferentiated Blue Bottom Group sediment: calcareous, glauconitic, fine sandstone of probable Southland age, sharply overlies the Oparara Member.

LIMESTONE CREEK LOG 4

Log 4 for the Limestone Creek area is very general, because the sequence is poorly exposed; it is taken largely from Wellman (unpubl.) and Wellman, et al. (1973). Wellman stated that approximately 80 m of "Glasseye Mudstone" rest on schistose greywacke; the contact is covered. The upper 0.2 m of the Glasseye Mudstone is bored (Wellman, unpubl., and Wellman et al., 1973), and the borings are filled with pebbles. Schist, granite, and quartz pebble conglomerate (basal unit, Stony Creek Limestone) overlies the bored horizon. Wellman (unpubl.) stated that the pebbles are elongated and compared them to pebbles found on shingle beaches. The conglomerate grades upwards into about 41 m of very thin- to thin-, wavy-bedded, yellowish-light brown to dark grey, fine pebbly to very coarse sandy echinoderm bryozoan biosparite. Substantial amounts of detritus are concentrated along the bedding planes; the total detrital content decreases in the upper half of the member. The limestone is uniformly coarse grained and lacks the large hemispherical bryozoan colonies noted in this member at the Stony Creek and Oparara localities.

A facies of the Oparara Member (a medium grey to light brown, well indurated, very fine sandy foraminiferal calcareous biomicrite of possible Pareora age) overlies the Stony Creek Limestone. The mudstone is bioturbate and contains numerous flattened cylindrical burrows. Chalcedony nodules are noticeable on weathered portions of the outcrop.

Calcareous, muddy very fine sandstone, a typical undifferentiated Blue Bottom Group sediment, overlies the Oparara Limestone.

KONGAHU POINT LOG 5

The base of the Kongahu Member is exposed at Kongahu Point, opposite Old Man Rock (S18/444101). A subtle gradation between the Paparoa Granite and lowest easily recognizable sedimentary rock--the Kongahu Member--is particularly interesting. Unweathered light colored granite grades upwards into a weathered zone several meters thick, which, in turn, becomes a very coarse pebble conglomerate with a non-calcareous, very micaceous, very coarse sandy matrix. This sediment passes vertically into a conglomerate/breccia of small to large, angular to subrounded granite boulders in a friable matrix of coarse to fine pebbly, very coarse sandstone. Thin, discontinuous bands of highly micaceous, muddy very coarse sandstone (angular grains) are common and impart an overall greenish color to the sediment. Overlying this sediment is a massively bedded, reddish, less micaceous conglomerate. This conglomerate consists of medium to large, angular to rounded granite boulders in a non-calcareous matrix of cobbles, very coarse pebbles, and very coarse arkosic sand. No sedimentary structures were seen, although there is a hint of a preferred fabric orientation. The maximum and intermediate axes of the boulders lie parallel to the bedding plane.

A series of four thick-bedded, slightly calcareous, graded beds overlies the very thick-bedded conglomerate. The graded beds feature sharp bases and 'welded' tops. Grading is crude but discernable; the maximum grain size at the base is approximately 20 mm and grades upwards to 1-2 mm. A possible channel fill, laterally equivalent to the lowermost graded bed, was noted in a poor exposure behind the hut at S18/446101 (Log 5). A further series of twelve, medium bedded, slightly calcareous graded beds crops out above a 5 m covered interval. These beds exhibit wavy bases and crude normal grading from fine pebbles to very coarse sand or coarse sand. Angular granite cobbles are scattered through the beds, which are separated by thin layers of dark grey sandy mudstone.

Approximately 30 m of very thick-bedded granite breccia with a pebbly matrix can be seen from a distance to the east near S18/449102. The Glasseye Mudstone first appears as medium-bedded mudstone, which punctuates the breccia-coarse sandstone sequence at irregular intervals. Several of the sandstone beds are lenticular and may be graded.

Dense bush and slips conceal the next 175 m (approximate) of the sequence. The Glasseye Mudstone commonly occurs in the next visible part of the sequence, where it alternates with thin to very thick beds of fossiliferous, very coarse to coarse sandstone: lithic feldsarenite (Kongahu Member). These coarse beds often have sharp, erosive bases and flat tops. Normal grading is occasionally present, and concentrations of mudchips frequently appear in the upper half of a bed. Grain size varies from large boulders to medium sand, but most commonly is a medium pebbly very coarse sand. Groove casts and loading structures are common. Burrowing is widespread, particularly on the bedding surfaces. Fossil and carbonate content increases upwards in the sequence, and the upper beds (Kongahu Member, Log 5) consist of angular, very coarse sandy bryozoan-echinoderm-red algal biosparite. Breccia beds are rare in the upper 100 m of the logged sequence. Zones of slumped or contorted Glasseye Mudstone are scarce. They are usually associated with very thinly bedded conglomerates or pebbly, very coarse sandy limestones.

The intercalation of well indurated Kongahu Member and moderately indurated Glasseye Mudstone beds, which was noted in the upper 150 m of the sequence, continues in the Falls Creek, Little Wanganui River, and Gentle Annie Point sections. The alternation of distinctive lithotypes characterizes the Little Wanganui Formation found along the coast between the Little Wanganui and Mokihinui Rivers.

A 0.4 m wide fault pug is exposed at the base of the cliff opposite Old Man Rock. This presumably marks the Kongahu Fault of Webb (1910); it trends nearly N-S. An alternating sequence of Glasseye Mudstone and Kongahu Member beds occurs on the western, downthrown side. Their aspect supports Webb's statement that the throw of the fault is in excess of 1000 feet.

FALLS CREEK LOG 6

The Falls Creek section includes all Little Wanganui Formation sediments that are found between Falls Creek and the base of Otahu Hill, a sheer coastal cliff 0.7 km south of the creek. The section consists of interfingering Glasseye Mudstone and Kongahu Member lithologies.

The Glasseye Mudstone (light grey, moderately indurated, very calcareous, silty mudstone) dominates this section. The very thin- to very thick-bedded mudstone units vary in induration and detrital content. Very thin discontinuous layers of fine sand commonly mark the indistinct bedding surfaces. Inorganic sedimentary structures are rare, but burrowing is abundant.

The Kongahu Member is generally light grey, well indurated, very poorly sorted, fossiliferous, muddy and medium bouldery to fine pebbly very coarse sandstone; subfeldsarenite. Detrital grains are subangular to subrounded. The beds show wide lateral thickness variations; several beds nearly 1 m thick pinch out within several meters. The average thickness of the beds is about 1 m. As recorded in the upper portion of Log 5, the beds usually display sharp, primarily erosive bases and flat tops. Groove casts are present on several of the basal bedding planes. Mud chips often occur in the upper portion of the beds. Grading is uncommon and contorted horizons are rare. One such horizon, located near sample UC 7458 I is associated with a wedge-shaped, muddy and bouldery conglomerate.

The Kongahu Member beds contain numerous poorly preserved fossils, including red algal, mollusc, brachiopod, and echinoderm fragments, benthonic foraminifera, and a variety of bryozoa. Pelagic foraminifera, siliceous sponge spicules, and echinoderm, mollusc and brachiopod fragments are plentiful in the Glasseye Mudstone. A well preserved fish was also recovered from the mudstone (App. III).

The Glasseye Mudstone is the dominant member in the inland reaches of Falls Creek. Well preserved leaf imprints and plant fragments are abundant and the mudstone yields a strong petroliferous odor when struck with a hammer (Webb, 1910). Beds of the Kongahu Member and slide/slump deposits are almost entirely confined to the coastal exposures.

LITTLE WANGANUI HEAD LOG 7

The Nile Group is well exposed along the south bank of the Little Wanganui River from the mouth of

Glasseye Creek to Little Wanganui Head, and south along the coast for about 1.1 km. Log 7 details approximately 290 m of sediment with ages spanning the lower Whaingaroan to Otaian-Altonian stages.

The "background" sediment (light grey, very calcareous, silty "Glasseye" mudstone) dominates the overall sequence. The mudstone appears to be fairly uniform throughout the section, varying only slightly in detrital content and induration. Nearly 100 m of lower-mid Whaingaroan Glasseye Mudstone crops out on the wave platform 1.1 km south of the Head at S18/498159. Slumps occur in the upper portion of the mudstone, which contains very thin bands of sandy biosparite (Kongahu Member).

In a cliff at S18/498158, three basic lithotypes appear: the "background" sediment--Glasseye Mudstone; shell-rich pebbly mudstone; and bouldery to pebbly, very coarse sandstone and sandy limestone--Kongahu Member. Pebbly mudstone, often containing large brachiopods and bryozoan fragments, is a distinctive, but rare lithology.

The pebbly mudstone at S18/498158 contains valves of the giant brachiopod Liothyrella magna and medium pebbles of granite in a muddy matrix (Fig. 5/8).

Kongahu Member beds are well exposed at beach level, south of the Head from S18/503163 to 499160. Approachig these deposits from the south, one is impressed by the immensity of the granite boulders contained in several of the beds. One boulder, accessible at low tide near

S18/503163, is 7.2 m in diameter. The boulder-bearing beds are generally lenticular on a large scale (often 100 m or more); they have flat or slightly undulating tops, and irregular, concave-up bases. The beds vary in thickness from 0.7 m to at least 11.5 m. The coarsest boulder beds (S18/500160 and 502162), when viewed at a distance from the wave platform, give the impression of being large submarine channel fills. The fabric of the channel fills is most commonly chaotic, although crude stratification is sometimes present, and normal grading is preserved in several of the finer conglomerates (Figs. 4/17-4/19). Mud clasts are concentrated in the upper half of several of the thinner and finer grained beds (Fig. 4/12). Very dark brown, finely laminated, carbonaceous mudstone containing numerous pelagic foraminifera (Fig. 4/15), commonly overlies these very thin to thick beds of coarse detritus. Soft sediment deformation features are common, particularly where thick- to massive-bedded conglomerates and breccias overlie mudstone. Clastic dikes, load casts, flame structures, soft sediment faults and contorted laminae abound. Very thin, resistant, sandy biosparite layers outline hydroplastic folds, which are frequent features of the Glasseye Mudstone.

Numerous lenticular beds of sandy biosparite, ranging in thickness from a few millimeters to nearly 3 m, characterize the upper third of the Little Wanganui Head exposure from S18/504164 to 507165. These beds contain a high percentage of bioclastic debris and resemble the sediments of the Kongahu Member that are found lower in the sequence between Falls Creek and Gentle Annie Point. Most of the beds are massive, although crude normal grading is occasionally present, and large mud clasts are commonly concentrated in the upper half of the beds. Groove casts frequently mark the base of the beds. The sandy biosparite beds often show evidence of burrowing; epichnial and hypichnial ridges and exichnial burrow casts are abundant (Chap. 4).

The Kongahu Member, which is poorly exposed along the south bank of the Little Wanganui River (from S18/507165 to 512162), is tentatively dated as Duntroonian. A comparison with lower Kongahu Member beds reveals several trends. The upper Kongahu Member beds contain fewer boulders and cobbles and have a higher carbonate content. The detrital grains in the upper Kongahu Member are largely subangular--a roundness increase over lower beds. The beds of upper Kongahu Member average 0.1-0.3 m in thickness but become thinner, less frequent, and finally absent in the upper part of the Little Wanganui Formation.

The upper Little Wanganui Formation consists almost entirely of Glasseye Mudstone. The mudstone is poorly exposed at low tide, on the south bank of the little Wanganui River immediately west of Glasseye Creek. Slight variations in induration and fissility characterize the mudstone. Zoophycus, Planolites, and Arthrophycus(?) traces abound. The upper one-third of the mudstone is slumped and in places penetrated by large clastic dikes.

The exposures of the Little Wanganui Formation in the middle reaches of Glasseye Creek consist predominantly of Glasseye Mudstone with very rare thin bands of sandy biosparite. Coarse boulder breccias and conglomerates are completely lacking, as in the inland reaches of Falls Creek.

The Oparara Member, present as a 3 m thick resistant limestone band of Otaian to early Altonian age, erosively overlies the Waitakian Glasseye Mudstone at Glasseye Creek. No angular unconformity was detected. The limestone is characterized by wavy and irregular bedding planes. Medium beds of hard bryozoan biosparite alternate with thin-bedded, softer, bryozoan-foraminiferal biomicrosparite. The basal 1 m has a slightly nodular appearance.

Amphistegina is an important constituent of the limestone, and large, nearly whole echinoderms and pectens are scattered through the more resistant layers. Detrital material comprises only about 1 % of the limestone; angular, very fine quartz sand is the most important constituent, although subrounded, fine pebbles of quartz are also present.

Typical, undifferentiated Blue Bottom Group sediment (bluish-grey, poorly indurated, calcite cemented, silty very fine sandstone) sharply overlies the Oparara Member.

GENTLE ANNIE POINT LOG 8

A portion of the lower Little Wanganui Formation is exposed at Gentle Annie Point. Foraminiferal studies date the section as early Whaingaroan; the stratigraphic position and lithology of the rocks support this age. The contact between the formation and the underlying gneissic-granite basement is covered, and can only be approximately located. The sediments strike in a NNE direction and are overturned to vertical.

The Kongahu Member is variable and occupies approximately two-thirds of the 188 m of exposed sediment. The member ranges from bouldery, fossiliferous, arkosic sandstone to fine pebbly, coarse sandy biosparite. The member is very thin- to thick-bedded, the beds usually having sharp, erosive lower contacts and flat upper surfaces. Detrital material ranges from fine silt very fine sand to very large boulders of granite and gneiss. Bryozoa, red algal and echinoderm fragments, and _Amphistegina_ sp. are the dominant fossils. Sedimentary structures are rare, although grading, basal groove casts and clastic dikes are present. Flattened, cylindrical, wandering burrows commonly cover the tops and bottoms of beds.

The dark grey, moderately indurated, silty, calcareous Glasseye Mudstone comprises the remainder of the section. The mudstone contains numerous pelagic foraminifera tests and sponge spicules. _Zoophycus_ and _Planolites_ burrow traces are common.

One of the more intriguing aspects of this section is the presence of superb groove casts on the overturned base of a bouldery, coarse sandy biosparite (Fig. 4/22) and an associated slumped/contorted horizon.

HAPPY VALLEY SADDLE TO CORBYVALE LOG 9

Logs 9 and 10 summarize the middle Tertiary sequence that is exposed along Highway 67. The sediments crop out in two distinct areas. The largest exposure (Log 9) stretches from 0.8 km north of Happy Valley Saddle to the northern edge of the Corbyvale valley. A smaller, more spectacular outcrop is the one found at View Hill Saddle. Log 10 is a compilation of the sections along the highway from View Hill Saddle to the Mokihinui River.

The lower 120 m of Log 9 consist of alternating medium to thick beds of dark brown, poorly indurated, slightly calcareous Kaiata Mudstone and thin beds of the Kongahu Member. Foraminifera-red algae biosparite comprises the well indurated Kongahu Member beds. The occassionally lenticular limestone beds have very sharp upper and lower contacts with the Kaiata Mudstone. The limestone is usually massive, although faint horizontal laminations are infrequently present.

A sharp change in lithology and direction of strike and dip at S18/532076 marks the probable position of an E-W trending fault with its upthrown side to the south. The southward-dipping Kaiata Mudstone and Kongahu Member beds are faulted against vertical Lower Duntroonian(?), very light yellowish-brown Glasseye Mudstone. The next 15 m of Glasseye Mudstone, which are adjacent to the fault, consist of thick beds of moderately hard, very calcareous mudstone with, softer, muddier bands, which contain numerous plant fragments. One 0.2 m thick layer of fissile, very carbonaceous, calcareous mudstone is present. A horizon of slumped Glasseye Mudstone, approximately 34 m thick, is visible at S18/531076. Glasseye Mudstone constitutes most of the remaining Little Wanganui Formation that is exposed on Highway 67.

A thin-bedded, horizontally laminated, very fine sandy, calcareous mudstone with numerous sponge spicules and pelagic foraminifera represents the Kongahu Member in a small vertical outcrop near the Glasseye Creek bridge. This sandy mudstone sharply overlies burrow-mottled, poorly indurated, slightly sandy, carbonaceous, very calcareous Glasseye Mudstone.

Poor exposures and sporadic cover characterize the section from Glasseye Creek to Happy Valley Saddle. Thin, softer, more muddy bands are dominant in this section of the Glasseye Mudstone. The mudstone is generally bioturbate, but burrow disrupted laminae are occasionally visible. A zone of ovoid concretions, preserving burrow traces, occurs at S18/537085 (Fig. 4/38) The well indurated concretions consist of very calcareous pelletoidal mudstone (sample UC 7463 C) and preserve large burrows, which are dark grey because of pyrite inclusions. The dip in this section is about 30° NNW and increases to about 65° toward Happy Valley Saddle.

Waitakian Glasseye Mudstone is erosively overlain by the Oparara Member at S18/553095, 0.8 km north of Happy Valley Saddle. This 6 m thick limestone of Altonian age is a well indurated, medium brownish-green, medium pebbly to very coarse sandy mollusc fragment-foraminiferal-bryozoan biosparite (base) which grades upwards into a very fine pebbly echinoderm-bryozoan-foraminiferal biosparite. The basal part of the limestone contains numerous fine to medium, rounded granite and gneiss pebbles.

Wellman (unpubl.) reported clasts of Glasseye Mudstone in the Oparara Member, but I found none.

VIEW HILL SADDLE LOG 10

A partial Little Wanganui Formation sequence is preserved on the western downthrown side of the View Hill Fault, which roughly parallels the highway near View Hill. The Glasgow Fault, and an offshoot of the View Hill Fault, cut out the lower part of the Little Wanganui Formation in the south, near the Mokihinui River. Log 10 presents the Kaiata and Little Wanganui Formation rocks that are preserved in the View Hill area.

The Little Wanganui Formation overlies approximately 100 m of Kaiata Formation. The dominant Kaiata Formation lithology is a medium to dark brown, poorly indurated, fissile, slightly calcareous mudstone, which is poorly exposed and faulted in places. The Kaiata

Formation mudstone that crops out immediately north of Corbyvale is less silty and more calcareous than that found near the Mokihinui River. Bands of irregular, well indurated, carbonate concretions are present in the lower portion of the Kaiata Formation. The upper Kaiata Formation is sandier and more calcareous, and it contains thin lenticular beds of well indurated, calcite-cemented, very fine sandstone. Horizontal and ripple laminae are commonly present in the sandstone.

The oldest Little Wanganui Formation sediments that were observed in the View Hill area crop out at the base of View Hill at S18/475010. The Glasseye Mudstone, a light brown, moderately well indurated, very calcareous mudstone with softer, muddier bands, comprises the bulk of the View Hill section. The mudstone contains few macrofossils, but leaf impressions and plant detritus are locally abundant. Foraminifera and sponge spicules are very common; however, the rock proved too well indurated to provide adequate foraminifera for dating purposes. The mudstone is largely structureless, although local bands of horizontal laminae occur. These laminae are commonly disrupted by burrowing.

Tubular burrows that are not generally apparent on the outcrop are commonly visible in sawn slabs. Zoophycus traces are very rare.

Very thin Kongahu Member beds are common in the upper half of the sequence. Generally these very thin beds pinch and swell irregularly and consist of medium sandy, muddy, foraminiferal-bryozoan-echinoderm biosparite.

Pebbles up to 11 mm are occasionally present. The thickness of the coarse layers varies from a few millimeters to 0.14 m, but averages about 10 mm.

A slump horizon, approximately 20 m in thickness, is well exposed on the highway immediately south of View Hill Saddle. The slump deposit is composed of Glasseye Mudstone with less indurated thin layers of Kongahu Member limestone. It is interesting to note that the thickness and frequency of the coarse biosparite Kongahu Member layers increases in the 5 m interval immediately below the slumped horizon. The induration variations on the slightly weathered road cut outline large recumbent hydroplastic folds, glide planes, clastic dikes and injection features. They are discussed further in Chapter 4.

The age of the slumped horizon has not been difinitely established. Three microfossil collections yielded no narrowly dateable foraminiferal species, but on stratigraphic evidence, a late Whaingaroan to early Duntroonian age is likely. There is no certain evidence to suggest that this slump horizon is correlative with the one north of Corbyvale. The slumps may not be synchronous, but they do represent the reaction of this sediment type to stress. Whether this stress and ensuing slumping were simultaneous over a large area is difficult, if not impossible, to determine. It is only certain that some kind of stress (earthquake, sediment overload, tsunami, storm wave, etc.) was present in late Whaingaroan to Duntroonian time, and caused slumping.

CHAPTER 4

SEDIMENTARY STRUCTURES

Sedimentary structures are unevenly distributed throughout the Nile Group. The Kohaihai Limestone is largely massive, but it contains sparse discontinuous coaly laminations in its lower part, and one group of cross-laminations in its upper part at Kohaihai Bluff. The Stony Creek Limestone is massive; the Oparara Member is structureless. The Glasseye Mudstone is predominantly massive, although horizontal laminations are occasionally present. The vast majority of sedimentary structures occur in beds of the Kongahu Member.

Massive Kongahu Member beds are common, although grading, horizontal laminations, groove casts, and load casts occasionally occur. Large channel structures, which are filled with Kongahu Member sediments, are present in the coastal cliffs south of the Little Wanganui River. Large-scale slumping (accompanied by clastic dikes) affects the alternating sequences of Glasseye Mudstone and Kongahu Member beds, which crop out along the coast and highway south of Little Wanganui.

MEGASTRUCTURES

Channel Structures

The Kongahu Member beds in the Little Wanganui Formation (exposed in the coastal cliffs from Little Wanganui to Gentle Annie Point) often fill features that resemble channels. At least 15 channels appear along the coast between Little Wanganui and Falls Creek. They are generally shallow forms with a few steeper cuts. The channel walls are sharply defined. The slope of the channel walls averages around 10°, but varies from a few degrees to nearly 40°. The channel infillings are commonly several meters thick; thickness varies from less than 1 m to over 12 m. Individual channels have an apparent width of between 10 and 60 m (Figs. 4/1-4/5). The channels often intersect each other (Figs. 4/1 and 4/2), but are not nested as in Walker (1975b).

Two main types of channel fill are distinguished. Type I is the most common and consists of lenticular very thin to thick, poorly to very poorly sorted, very coarse sandstones (Kongahu Member). The beds are usually massive, although grading and faint horizontal lamination are occasionally present. The channel fill may consist of one very thick bed or, more commonly, several beds alternating with very thin to thin beds of Glasseye Mudstone. The channel fill is often muddy because of biological mixing with Glasseye Mudstone layers; it also commonly contains mudstone clasts. The lithology of the Type I channel fill varies considerably throughout the Little Wanganui Formation. Near the base of the Formation at Kongahu Point, the channel fill consists of fossiliferous, calcite-cemented, medium to coarse pebbly, very coarse sandstone. Very coarse sandy, red algal bryozoan-foraminiferal biosparite represents

Figure 4/1 Panoramic view of cliff section at S18/503163 showing channel structures.

Figure 4/2 Panoramic view of channel structures at S18/504165 showing Types I and II infillings.

Figure 4/3 Three figures forming a panoramic view of beds of the Kongahu Member and associated channel structures on coastal cliffs south of Little Wanganui Head at S18/504165.

Figure 4/4 Same as Figure 4/3.

Figure 4/5 Same as Figure 4/3.

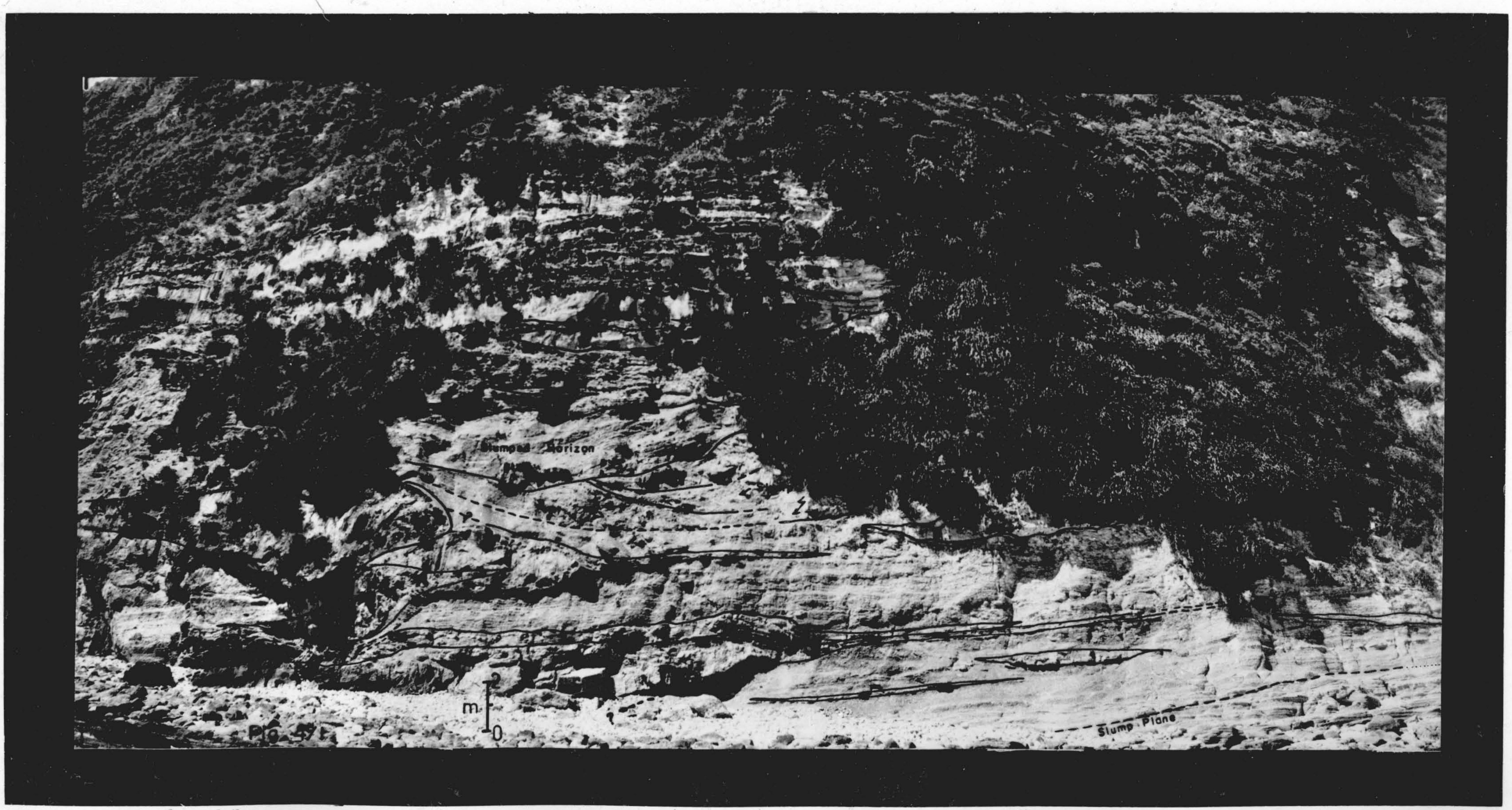


Fig. 47

Fig. 4/2

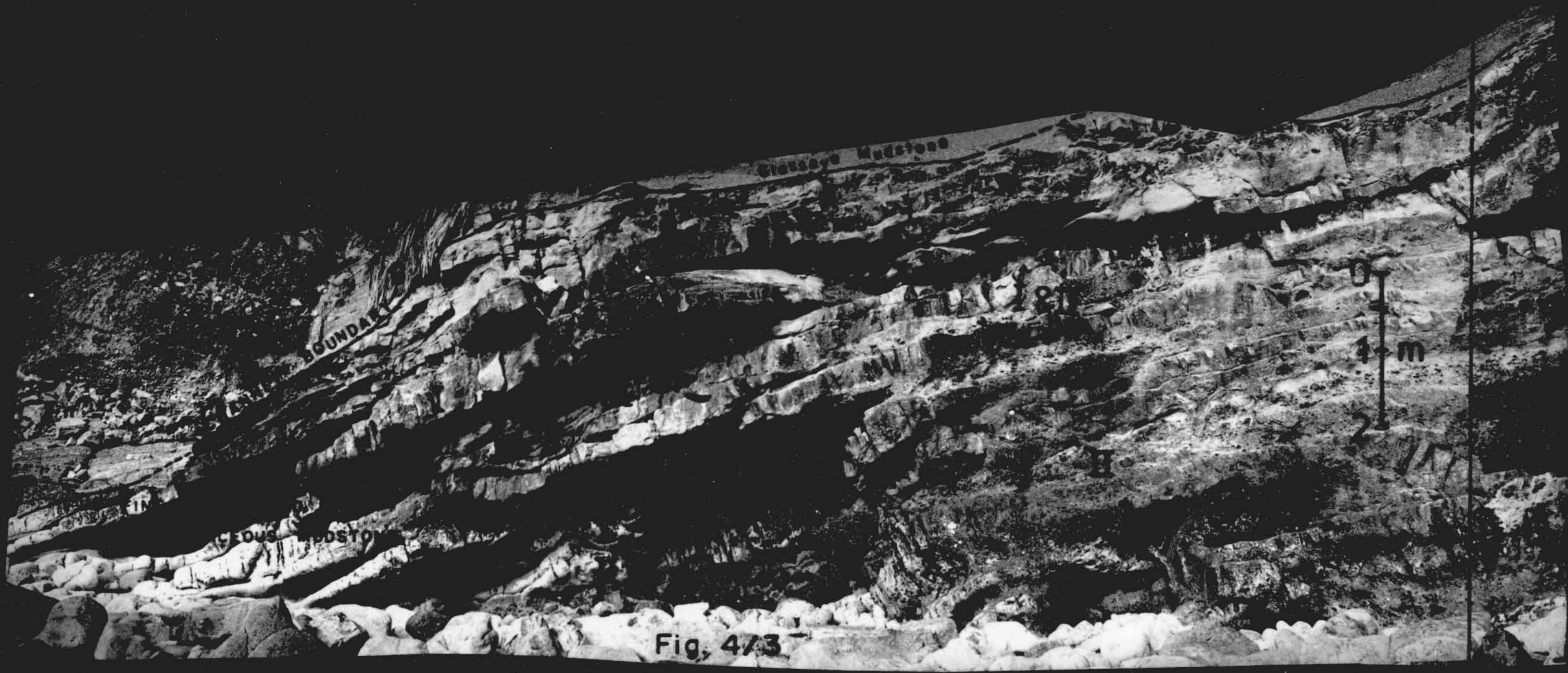


Fig. 4/3


0
1 m
2
MEMBER
SLUMPED
HORIZON ?
Fig. 4/4

Fig. 4/5

the Type I infilling in the upper part of the Formation near Little Wanganui Head.

Type II infillings consist of medium to very thick-bedded, very poorly sorted, angular to subangular granite breccia or conglomerate. The beds are commonly massive and less commonly stratified. Very crude normal grading is present in some stratified layers. The conglomerates/breccias are generally matrix-supported, although lenses of clast-supported conglomerate/breccia occur. The Type II matrix consists of slightly muddy, calcite-cemented, very coarse pebbly, very coarse sandstone: lithic feldsarenite. Bryozoa, benthonic foraminifera, and fragments of red algae are the dominant fossils. The Type II infillings contain granite boulders up to 7 m in diameter, although small boulders and very coarse pebbles are the most common granite clast sizes.

The above channel fill types form the end members of a continuously variable series of channel infillings. Large channels often display a whole spectrum of channel fill types (Figs. 4/2-4/5). The base of the channel may be filled with unstratified bouldery conglomerate (Type II infilling) which grades upwards into stratified, very coarse pebble conglomerate, which, in turn, may grade upwards and laterally into pebbly, very coarse sandy limestone (Type I infilling). The processes that controlled the excavation and infilling of the channels could affect the size and compositional segregation of the infilling materials. A great deal of work, both descriptive and theoretical is necessary before a satisfactory understanding of these structures and their genesis can be attained.

Slump Structures

Slump structures resulting from the penecontemporaneous, subaqueous sliding of large masses of sediment are frequently seen in the Little Wanganui Formation south of Little Wanganui (Figs. 4/6-4/8). Slump deposits occur throughout the Formation and range in age from early Whaingaroan to Waitakian.

The slumped sediment consists of alternating Glass-eye Mudstone and Kongahu Member layers. The slump masses average 2 m in thickness, but range from less than 1 m to over 30 m in thickness.

The slumps are of the open-cast type (cf., Corbett, 1973), which implies that slumping occurred on the seafloor before burial. The slump sheets moved as individual masses downslope over decollement surfaces, which are subparallel to bedding. The type of movement whereby individual layers break loose, slide downslope, and produce a jumbled sedimentary breccia is absent (Reineck and Singh, 1973).

The majority of the slumps in the study area fall somewhere between coherent and semicoherent slumps (Corbett, 1973). Coherent slumps retain much of the original bedding and move by gravity induced plastic flow. A few individual slumps and parts of other slumps could be classified as incoherent slumps (i.e., slumps which move downslope by viscous fluid flow and which preserve very

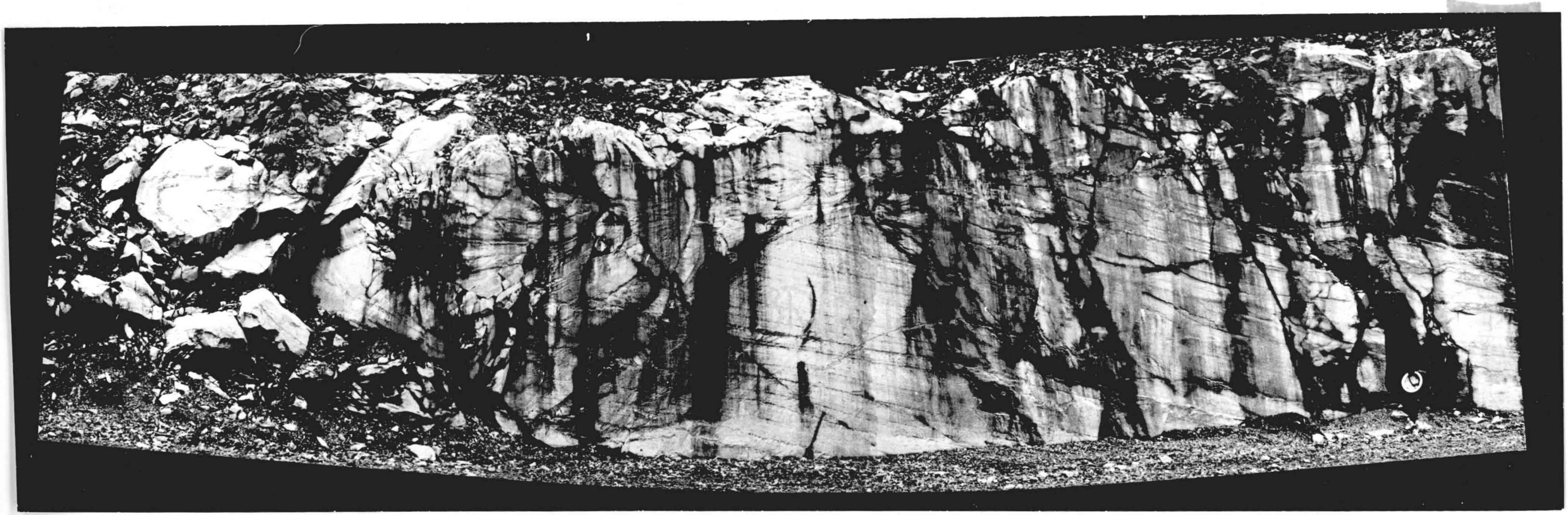
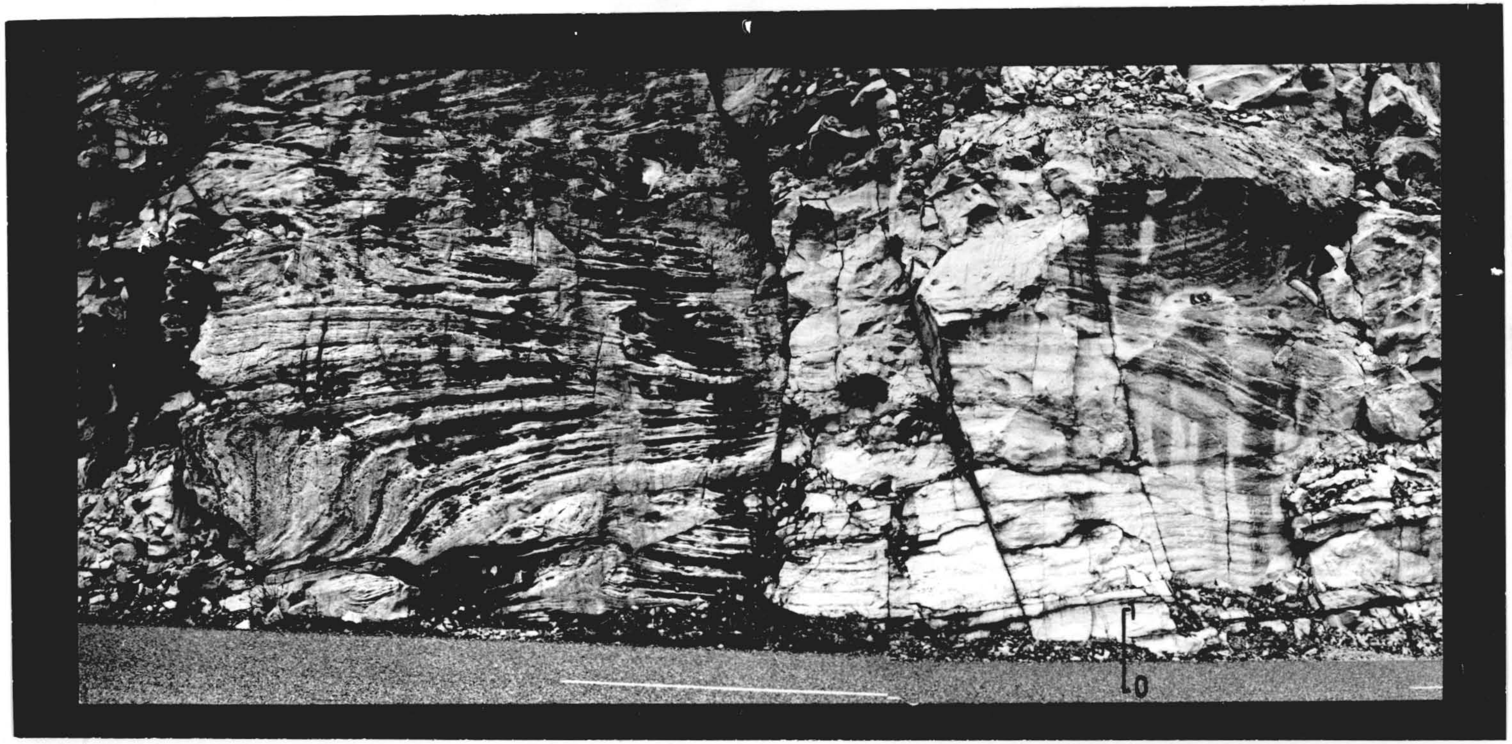


Figure 4/6 Portion of large slump, exposed on Highway 67 near View Hill Saddle at S18/476013. Slump sediment consists predominantly of moderately indurated Glasseye Mudstone and thin to very thin beds of less indurated Kongahu Member sandy limestone. Man in lower right corner is 1.9 m tall.

Figure 4/7 Large hydroplastic folds and slump mass near View Hill Saddle at S18/476013.



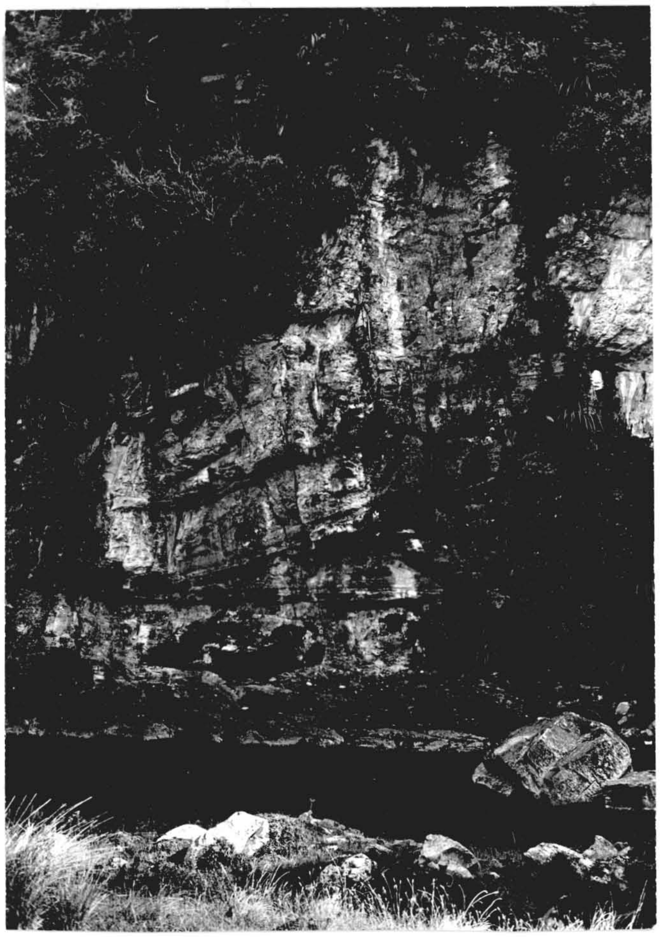


Figure 4/8 Large scale bedding discordance caused by rotational slump (?) near mouth of Falls Creek (S18/486138).

little of the original bedding). The Elliott (1965) classification would place most of the slumps in its slurry/slump-bedding division.

Portions of the slump at View Hill are shown on Figures 4/6 and 4/7 . The base of the slump appears to be an uneven decollement surface below which the sediments are undisturbed. The Glasseye Mudstone is slumped into a series of intricate recumbent folds, immediately above the decollement surface. The folding pattern is outlined on the slightly weathered outcrop by thin layers of poorly indurated, sandy biosparite (Kongahu Member). The folded sediment is attenuated or thickened and in places the original bedding form is entirely lost. The View Hill slump may be composed of either one large slump, or several smaller slumps that occurred almost simultaneously and are not now distinguishable. The slumps are of the semichoherent type and may have moved downslope by viscous fluid flow (Corbett, 1973). The plastic sediment folded, flowed, and slumped in response to compressional forces near the toe of the slump.

Slumping occurs " ... when shear stresses acting downslope exceed the shear strength of the sediment along any potential surface of failure" (Lewis, K. B., 1971, p. 97). An increase in pore pressure or a spontaneous loss of cohesion (like liquification of thixotropic sediment by sudden shock or vibration) may reduce the shear strength of a sediment (Burns, 1963).

Tilting, oversteepening, and overloading can increase the shear stresses acting on a sediment.

Tilting of the seafloor, probably accompanied by earthquake tremors, could initiate slumping. Oversteepening may operate at the top of a shelf where deposition of coarse clastic sediments forms an embankment. Coarse sediments with a high angle of repose may spontaneously slump (Rich, 1950). Sedimentary overloading occurs when the rate of sediment supply exceeds the rate of consolidation (through compaction and diagenesis--Burns, 1963). Overloading can cause clays to yield at depth; slumping will occur if the sediment reposes on a slope.

Slump structures are associated with rapid sedimentation, but are not confined to any single depositional environment. K. B. Lewis (1971) recorded modern slumping off the east coast of New Zealand on slopes of 1°-4°, although slumping can occur on slopes of only 0.5° (Dott, 1963).

Soft sediment faults with small displacements (e.g., Fig. 4/9) frequently occur in the coastal exposures of the Little Wanganui Formation. Beds are squeezed and attenuated along the fault planes. Sediment with a stiff, plastic consistency would undergo such deformation if faulted.

Differential compaction, slumping of cohesive plastic sediments, and tectonic disruption of unconsolidated sediment can cause penecontemporaneous faulting. Differential compaction and slumping were probably the principle causes of soft sediment faulting in the study area.

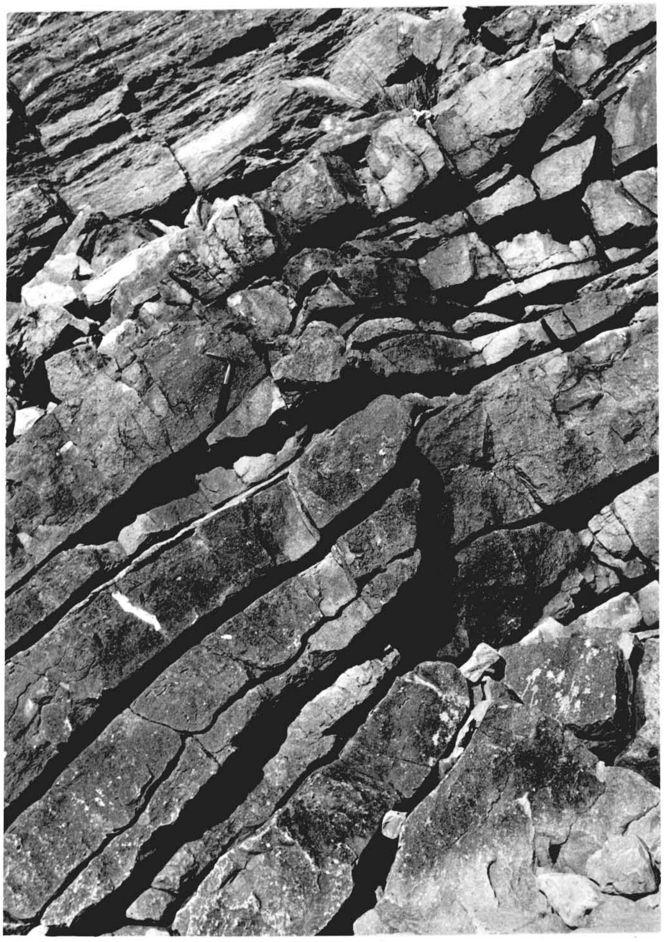


Figure 4/9 Soft sediment fault south of Little Wanganui Head (S18/ 504164). The faulted rocks consist of thin- to thick-bedded very coarse pebbly biosparite (Kongahu Member) interbedded with thin to very thick beds of Glasseye Mudstone. Length of hammer is 33 cm.

Figure 4/10 Discordant bedding plane (slump plane?) separating Glasseye Mudstone from slumped mixture of Glasseye Mudstone and Kongahu Member limestone at Little Wanganui Head. Length of hammer is 33 cm.

Slump planes, erosion surfaces, and Kongahu Member beds occasionally truncate the channels and slump deposits. The erosion surfaces may be attributed to a non-depositional phase of channel production. Alternatively, erosion by water currents or other depositional processes, which have left no trace in the sediments, may have been responsible for the erosion planes (Figs. 4/10-4/11).

INTERNAL ORGANIZATION AND STRUCTURES

Massive Bedding

Massive bedding, the absence of structures regardless of bed thickness (Pettijohn and Potter, 1964), is characteristic of most rocks in the study area and is a result of bioturbation. The massive units vary in thickness from a few millimeters to several meters. Bounding surfaces are usually gradational and all show some evidence of burrowing.

Horizontal Lamination

At Falls Creek (samples UC 7463 B and 7458 M) and along Highway 67, bands of muddy Kongahu Member limestone contain faint, discontinuous, horizontal laminations, which reflect the alignment of flakes of mica and carbonaceous matter.

Alternations of light-colored muddy biosparite and cleaner biosparite that is rich in dark, pyritized bryozoa comprise the laminations in the lower two-thirds of a muddy 30 mm thick bed of Kongahu Member near View Hill

Figure 4/11 Discordant bedding planes 1.5 km south of Little Wanganui Head (S18/498158) indicated by dotted lines. Lower discordant contact may be a slump plane. Upper discordant contact may have been related to the formation of the large channel, which is seen in the upper right corner.

Saddle (Fig. 4/12). The thinly laminated to laminated Kongahu Member sediment (Fig. 4/13) contains very thin, silty, horizontal laminae, which are marked by slight differences in carbonaceous content.

Thin fossiliferous sandstone and sandy limestone beds of the Kongahu Member, which crop out along the Little Wanganui coast, display occasional dark, horizontal laminae. Sometimes these laminae mark the partly eroded boundary between two Kongahu Member beds (Fig. 4/14). The dark layers consist of muddy, finely comminuted plant debris and carbonaceous, muddy foraminiferal biosparite. Sets of these fine (up to 0.1 m thick) laminations are usually found above or associated with calcareous Kongahu Member beds (Figs. 4/14-4/16). Compaction and loading of adjacent sediments deforms many of the dark laminae.

Vague, fine, horizontal laminations are noticeable on some broken surfaces of Glasseye Mudstone. The laminations, which are unmarked by burrowing, consist of dark, carbonaceous sediment, and concentrations of silt. Low-energy water currents were probably responsible for most of the laminations in the Glasseye Mudstone.

Grading

Crude normal grading is present in some of the Kongahu Member beds along the coast, and in one bed at View Hill Saddle (Fig. 4/12). In several instances, normal size grading and compositional grading occur

Figure 4/12 Sawn and varnished slab of Kongahu Member (UC 7458 O) from View Hill Saddle. (1) very sharp, erosional base, not well shown in photo; (2) graded zone--fine gneiss pebbles at base, coarse sand at top; rock is fine pebbly-coarse sandy bryozoan shell fragment biosparite; (3) large, slightly distorted mud clasts; (4) water escape structure(?); (5) parallel laminated zone with small mud chips in upper part; arrow points to boundary with underlying graded bed; (6) burrow; (7) laminated very calcareous and silty Glasseye Mudstone.

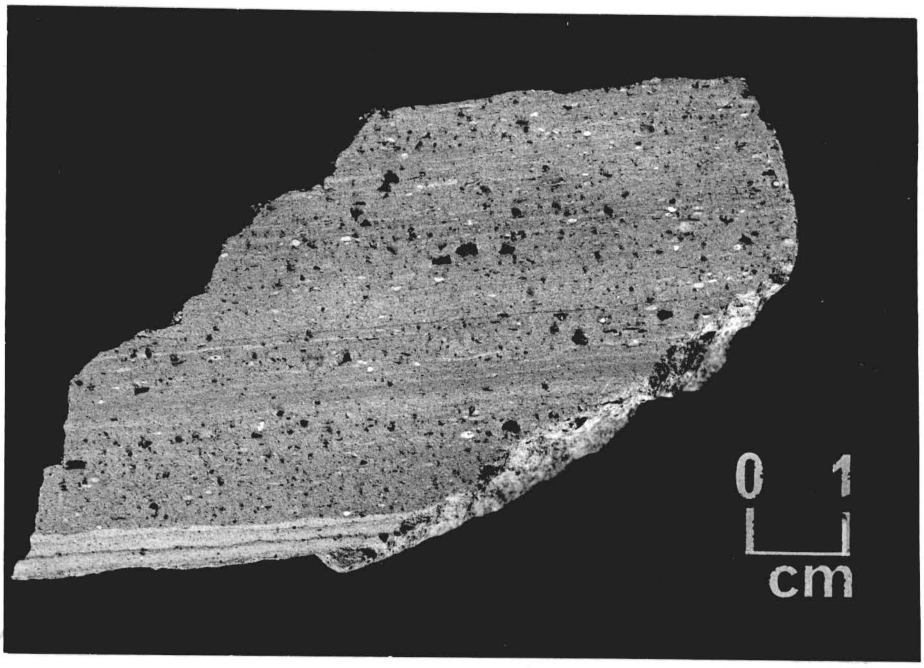


Figure 4/13 Sawn slab from View Hill (sample UC 7458 H) of Kongahu Member and Glasseye Mudstone. Note very fine parallel laminations and scattered very coarse sand grains. Interpreted to represent a distal turbidite deposit.

Figure 4/14 Series of massive or crudely graded beds of Kongahu Member separated by irregular thin laminations of carbonaceous mud. Note large gneiss clast in middle and the distortion of the layers due to compaction and loading. Little Wanganui Coast near S18/498158). Hammer is 33 cm long.

Figure 4/15 Coarse sandy bioclastic Kongahu Member limestone (1) along the coast are often associated with laminations or very thin beds of dark carbonaceous mudstone (2). Limestone bed at (1) may be a series of at least five redeposited units separated by faint carbonaceous laminae. Note that loading structures near the coin are slightly deformed by lateral adjustment of the overlying bed to the left(?). Water escape structures are visible at (3). Little Wanganui coast near S18/503164. Coin diameter is 32 mm.

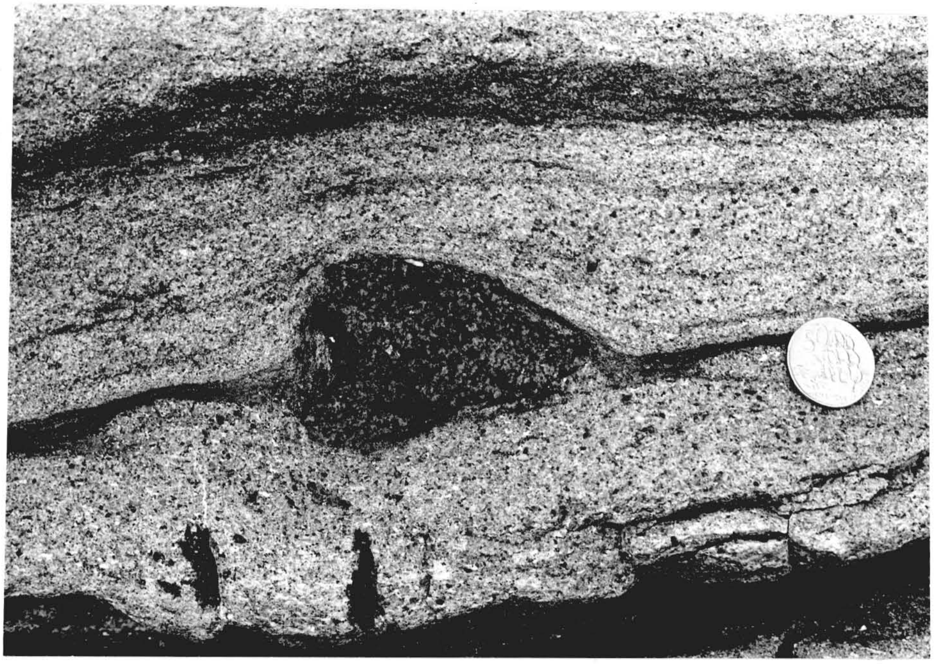


Figure 4/16 Close-up of finely laminated dark carbonaceous mudstone with fossiliferous very coarse sandy Kongahu Member. A 0.1 m diameter granite clast rests on top of the lower arenite. Little Wanganui Coast near S18/503164. Coin diameter is 32 mm.

Figure 4/17 Crudely graded bed of Kongahu Member from Kongahu Point. Note the finer basal layer and the burrow casts on the top of the bed. Diameter of lense cap is 55 mm.

within the same bed. The base of a bed occasionally contains a large amount of coarse detrital sediment, while the upper part consists primarily of coarse bioclastic material. Inverse grading is exceptionally rare.

Graded beds vary in thickness from a few centimeters to nearly one meter, and occur singly or in groups (Figs. 4/12, 4/14 and 4/17-4/19). When found singly, the upper and lower contacts with the enclosing mudstone are very sharp. Contacts between individuals in groups of graded beds are occasionally sharp and erosional, but they are more often welded and gradational or obscure. Figure 4/18 shows a series of welded graded beds.

BEDDING PLANE FEATURES

Groove Casts

Groove casts are relatively abundant along the coast south of the Little Wanganui River where the Kongahu Member overlies Glasseye Mudstone. The best exposures lie near beach level where the soft mudstone has been eroded, or high in the cliffs where the underlying mudstone has fallen away. The structures are predominantly rectilinear elevations, 10-400 mm in width, and usually continuous over the exposed surface, which may be several meters long. The groove casts average 60 mm in width and usually stand 10 mm in relief. The majority of the structures are plain, unadorned

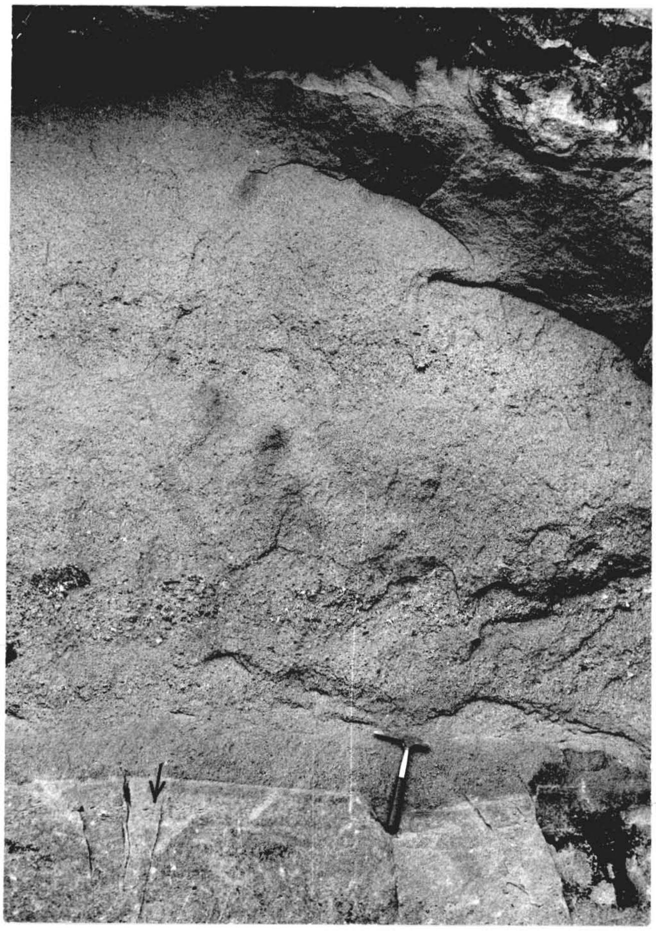


Figure 4/18 Series of graded Kongahu Member beds showing both sharp and welded interbed contacts. Grading is very crude and several beds appear massive. Note large granite cobble near top of one layer. Arrow points to concentration of weathered mud chips contained in lower part of one unit. Small soft sediment fault is present immediately to the left of the handle of the hammer. Length of hammer is 33 cm.

Figure 4/19 Overturned graded Kongahu Member bed from Gentle Annie Point. This bed exhibits both normal grading and compositional grading (arrow points to younging direction). Note the sharp upper contact and the sharp undulating lower contact. Many of the pebbles are algal coated indicating derivation from a high energy environment within the photic zone. Lense cap is 55 mm in diameter. (From a color slide by the author).

ridges, which occur in groups of between 2 and 20 individuals (Figs. 4/20 and 4/21). The individuals always trend in the same direction. Groove casts are seldom associated with other sole markings, but load casts are locally present.

There are extrordinary groove casts on the base of an overturned Kongahu Member bed at Gentle Annie Point (Figs. 4/22-4/24). These are large ridges, about 0.4 m wide and up to 0.2 m high, and vary in exposed length from 1-4 m. The casts follow slightly sinuous paths, probably the result of compaction and minor soft sediment deformation. A series of small colinear ridges follows the length of the structures. The small ridges exactly coincide with irregularities on the surface of a granite block tool, which is preserved at the end of the largest groove cast (Fig. 4/22). The granite block is the only <u>in situ</u> tool that is seen in the study area and it gives the structure a definite directional sense (see below).

Groove casts have little environmental significance and are characteristic of a wide variety of sedimentary environments. They are often associated with flysch sediments, but have been known to occur in very shallow water where waves, tidal-borne objects, and swimming animals have gouged lineations in mud (Reinich and Singh, 1973).

The groove cast trends vary widely (Fig. 4/25). Some causes of trend variations are: (1) observational and plotting errors; (2) folding and faulting of the strata;

Figure 4/20 Interlayered sequence of soft Glasseye Mudstone and pebbly-sandy Kongahu Member. Groove casts, visible on the bases of the two thick Kongahu Member beds, trend down the page (oblique markings are weathering stains). The center very thick bed is strongly lenticular and pinches out completely two meters to the right of the margin of the photograph. Photo taken immediately south of Little Wanganui Head. Man is 1.9 m tall.

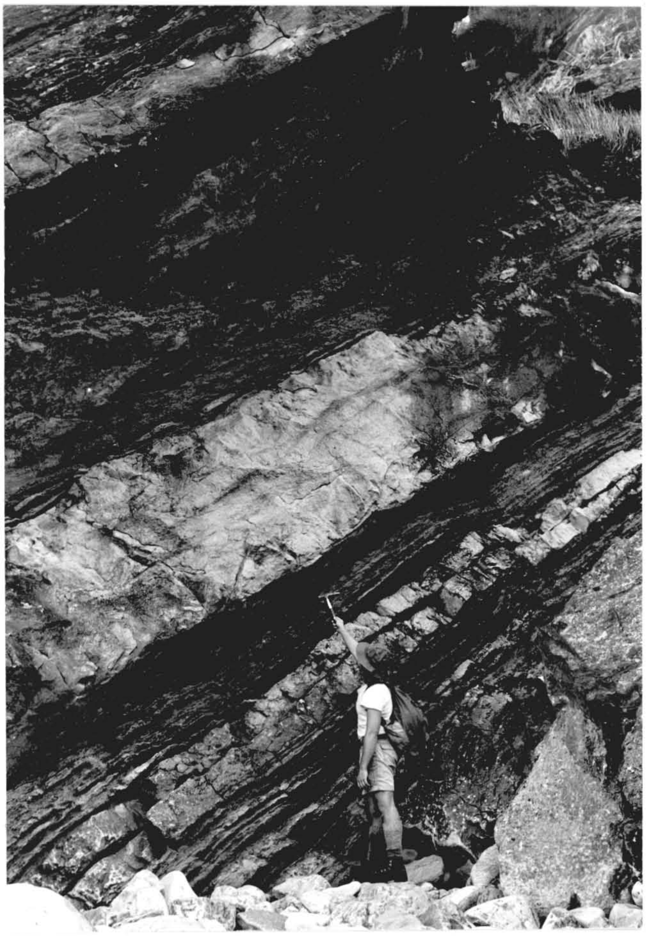


Figure 4/21 Group of groove casts on base of bed of Kongahu Member at beach level near Little Wanganui Head. Note presence of scattered boulders and cobbles, particularly the large subrounded granite boulder near the hammer. Hammer length is 33 cm.

Figure 4/22 Slide marks (groove casts) on base of overturned granite boulder Kongahu Member bed, Gentle Annie Point. Note the three large striated individuals and the granite boulder tool at the middle top. (From a color slide by the author).

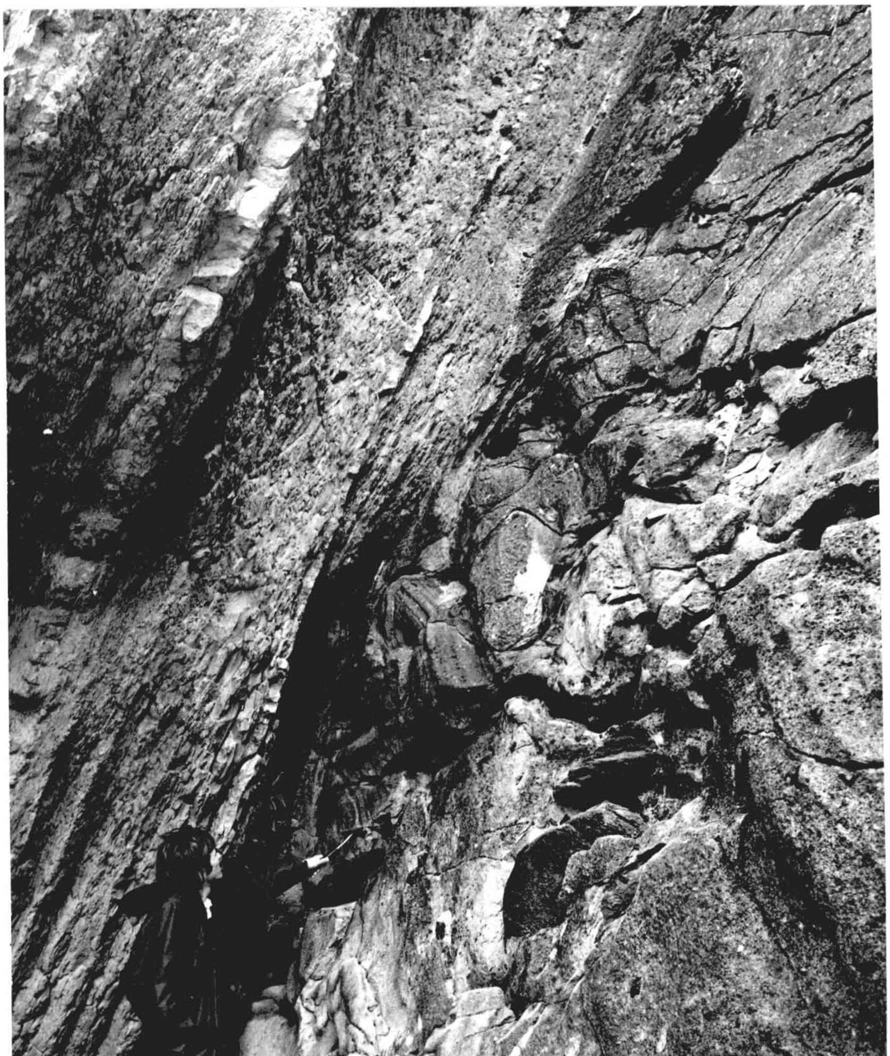


Figure 4/23 Close-up of lower slide marks emphasizing the numerous striations caused by irregularities of the tool boulders. Slightly irregular path of slide mark is probably due to compaction and soft sediment deformation. Hammer length is about 30 cm. (From a color slide by D. W. Lewis).

Figure 4/24 Close-up of upper slide mark. Note how longitudinal striations conform perfectly to the irregular ridges on the granite boulder tool. Exposed width of tool is 30 cm. (From a color slide by the author).

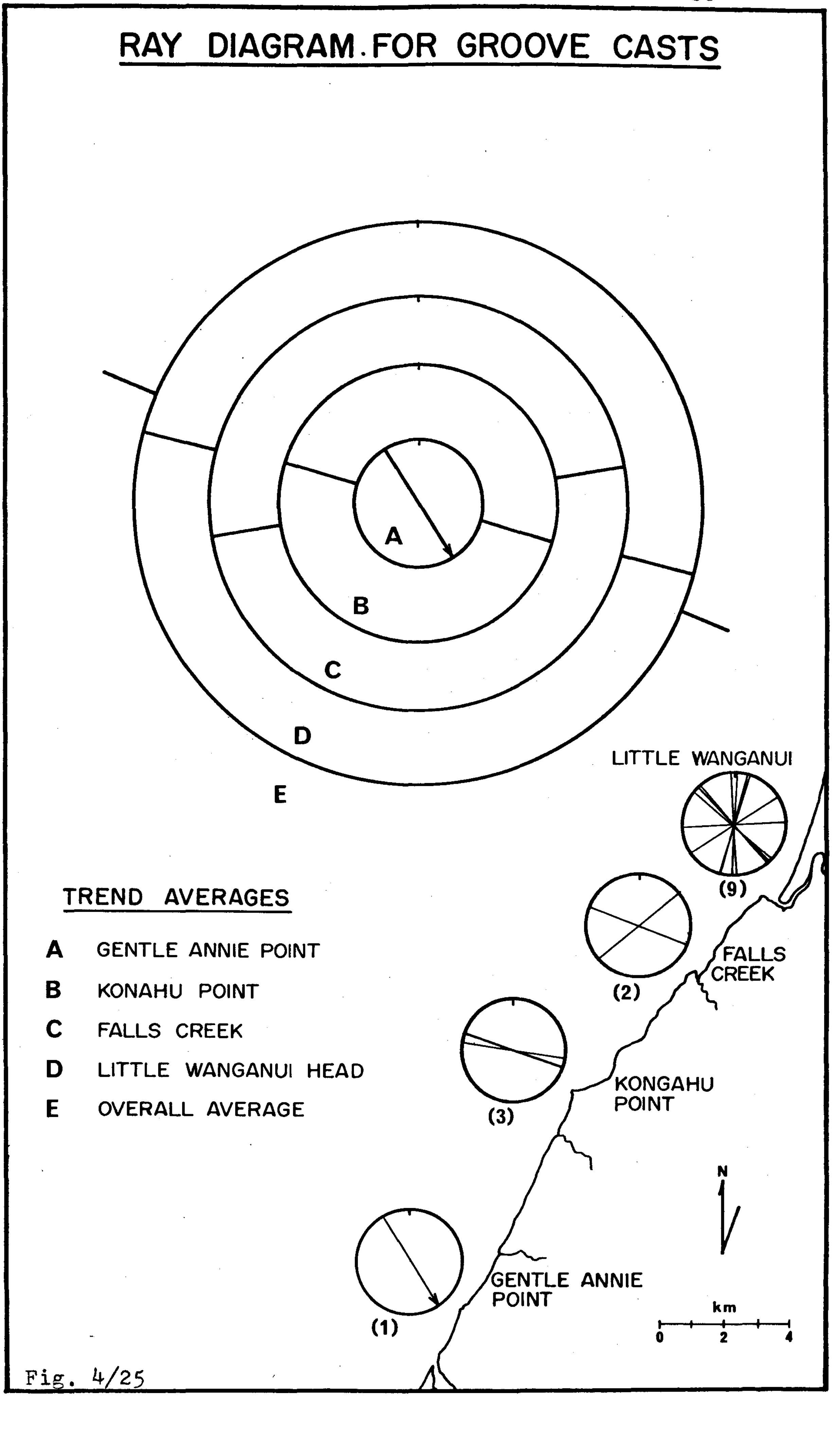

RAY DIAGRAM FOR GROOVE CASTS
A
B
C
D
E
TREND AVERAGES
A GENTLE ANNIE POINT
B KONAHU POINT
C FALLS CREEK
D LITTLE WANGANUI HEAD
E OVERALL AVERAGE
LITTLE WANGANUI
(9)
(2)
FALLS CREEK
(3)
KONGAHU POINT
N
(1)
GENTLE ANNIE POINT
km
0
2
4

Fig. 4/25

(3) rotational slumping of large masses of sediment, not detected on outcrop; and, (4) variations in direction of emplacement. The overall average shows a rough NW-SE trend. The *in situ* tool at Gentle Annie Point indicates that the Kongahu Member sediment originated in the west and moved to the east.

Load Casts

Load casts are sparse in the Little Wanganui Formation where sandy beds of the Kongahu Member overlie Glasseye Mudstone. The structure always appears as irregular lumps on the base of Kongahu Member beds (Fig. 4/26). The differential settling of sandy sediment over a less dense, thixotropic mud probably caused the structure (cf., Dzulynski and Walton, 1965). Scouring of the mud by currents or redeposited sediment may have played some role in load cast formation.

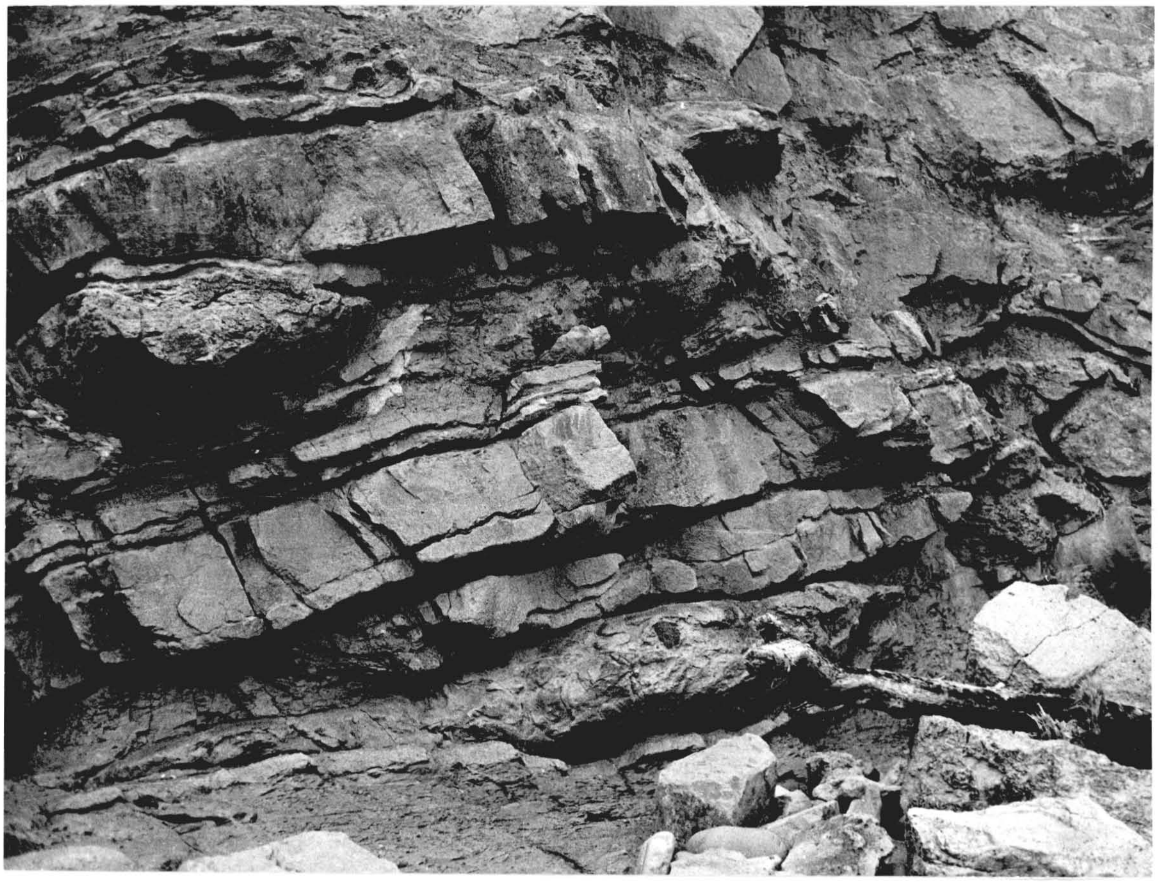
Load casts have no particular environmental significance, because they can be found in any environment in which sand is deposited on top of hydroplastic mud.

Slump Balls

Slump balls (synonyms: pillow structures, ball and pillow structures, flow rolls, pseudonodules; see Kuenen, 1949; Dzulynski and Walton, 1965; Pettijohn and Potter, 1965) are sparsely distributed through the lower part of the Little Wanganui Formation between Kongahu Point and Falls Creek. The structures occur where Kongahu Member sandy limestones overlie Glasseye Mudstone (Fig. 4/27).

Figure 4/26 Load casts on base of beds of Kongahu Member at Kongahu Point. Upper bed is 1.0 m thick.

Figure 4/27 Slump balls in alternating sequence of poorly indurated Glasseye Mudstone and well indurated Kongahu Member near Kongahu Point (S18/466117). Lower slump ball is about 1.0 m thick.



Groove casts and well developed load casts are commonly associated with the slump balls.

The slump balls are ellipsoidal masses of muddy, sandy limestone and fossiliferous, muddy sandstone; they are 1.5-3 m long and about 0.6 m thick. The exterior of the structures is smooth to very rough and wrinkled. The slump balls either lack internal structure or show rolled-up laminations, which appear cup-shaped in cross section.

The presence of numerous load casts in the Kongahu Member and the cup-shaped internal structure of the slump balls suggest that foundering was the principal causal factor (cf., Kuenen, 1949 and 1965; Dzulynski and Walton, 1965). Liquifaction of the substratum by shaking (e.g., earthquakes) could have caused foundering. Slump balls are not restricted to any particular sedimentary environment, although they are indicative of rapid sedimentation.

MISCELLANEOUS STRUCTURES

An association of clastic dikes and slumped or contorted beds is common in the study area. The literature (see Bouma, 1962 for examples) widely reports this association. The dikes vary in degree and dirction of penetration, shape, size, and composition. The composition of the dikes ranges from re-crystallized carbonate mud (Fig. 4/28) to coarse sandy fossiliferous limestone (Fig. 4/29). The dike margins are sharp and discordant. A few clastic dikes penetrate the overlying strata as

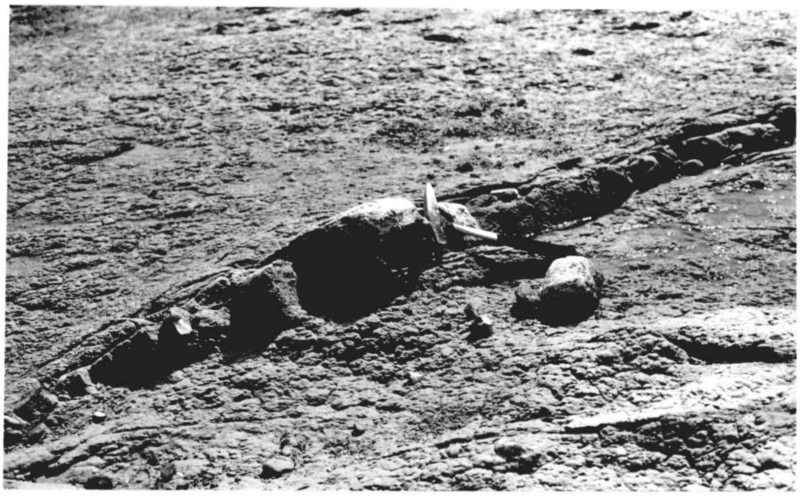


Figure 4/28 Clastic dike cutting through slumped Glasseye Mudstone. Dike material is pyritiferous muddy foraminiferal biomicrosparite. Hammer is 33 cm long. South bank of Little Wanganui River near S18/512163. (From a color slide by the author).

Figure 4/29 Contorted sandy limestone (Kongahu Member) with clastic dikes penetrating into surrounding Glasseye Mudstone. Dike margins are gradational in places. Falls Creek (S18/483141). Hammer is 33 cm long.

thin sheets, which are nearly perpendicular to bedding. Most of the dikes were emplaced when overlying sediments slumped and fractured as in Figures 4/28 and 4/29. In other cases, loading and possible sudden liquification was the cause of intrusion (Fig. 4/30).

Figures 4/12 and 4/15 show several water expulsion structures on the base of a Kongahu Member bed. Rapidly buried, soft, uncompacted sediment may trap large amounts of excess water. As compaction proceeds the excess water in the covered sediment may be forcefully expelled along planes of weakness in the confining unit. The expelled water may carry considerable amounts of clay minerals and fine organic detritus. The altered grain orientation in the confining unit and a color difference, resulting from the filtering of the expelled fluid, delineate the expulsion path. In three dimensions the expulsion paths are tubes or irregular, near-vertical sheets, which widen towards the base. The structures are dark colored, because of the filtered organics and mud, and they tend to fade away in the upper portions of the confining bed.

Structures resembling flame structures are rare in the Kongahu Member (Fig. 4/31).

Small scale planar cross lamination is very rare in the study area. One faint 0.4 m thick set of indistinct cross lamination occurs in the upper Kohaihai Limestone (Ld) at Kohaihai Bluff.

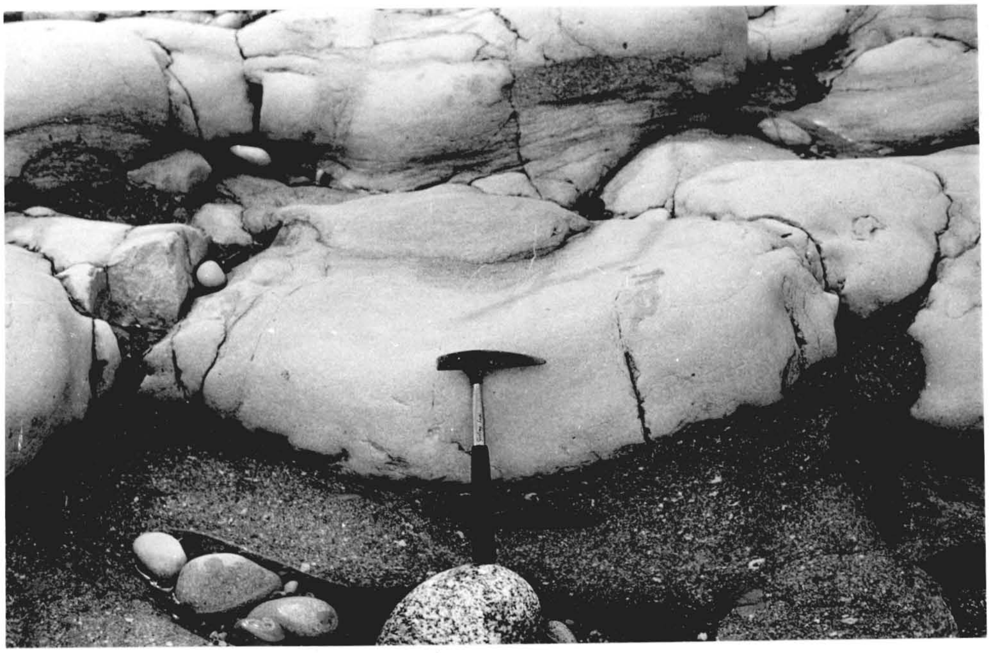


Figure 4/30 Clastic dikes (composed of muddy sandy red algal-bearing Kongahu Member) penetrating sandy bryozoan-algal foraminiferal biosparite (Kongahu Member). Dikes may have originally been load structures(?). Little Wanganui Head area. Hammer length is 33 cm. (From a color slide by the author).

Figure 4/31 Possible flame structure which lies at the base of a major channel structure, Little Wanganui Head near S18/503163. (1) silicified foraminiferal Glasseye Mudstone; (2) very coarse sandy fossiliferous mudstone, probably redeposited; (3) very coarse sandy bryozoan-algal biosparite (Kongahu Member) with scattered large granite boulders. Coin diameter is 32mm.

BIOGENIC SEDIMENTARY STRUCTURES

An ichnocoenosis, consisting of perhaps six ichnogenera, is found in the study area. Burrow mottling is common throughout the Nile Group, but distinct trace fossils are limited to the alternating Kongahu Member-Glasseye Mudstone sequence, which is found along the coast from Little Wanganui to Gentle Annie Point.

The traces are dominantly fodinichnia and rarely domichnia (terminology cf., Seilacher, 1953). The following descriptions indicate, where possible, the similarities with ichnogenera found in Hantzschel, 1975.

Type I *Planolites*(?)

Planolites is the dominant burrow type found in the Glasseye Mudstone (Fig. 4/32). These subcylindrical, infilled "stopftunnels" wind in typically irregular, gently sinuous paths. The burrows have ovoid cross-sections (compacted?), which average about 1.5 cm in diameter. The trace fossil does not appear to branch and it follows a path more or less parallel to the bedding plane. External ornamentation is usually lacking, although very faint transverse laminae are present on some samples. Sediment, which is sometimes finely laminated, fills the burrow. The sediment infilling is of the same character as the burrowed lithology, thus the trace may be classified as an infilled endichnial burrow (Martinsson, 1970). The structures are undoubtedly feeding traces that are filled with sediment that has

Figure 4/32 Type I ichnofossil, Planolites(?), from Waitakian Glasseye Mudstone north of Happy Valley Saddle. Lebensspur lightly outlined in pencil. Scale in centimeters. Photo by A. Downing.

Figure 4/33 Type II (small) ichnofossil resembling Arthrophycus from Duntroonian Glasseye Mudstone near mouth of Little Wanganui River Note Y-shaped branching and meniscus internal structure. Burrow is filled with alternating layers of calcareous mudstone and coarse sandy, Amphistegina mudstone. Diameter of coin is 32 mm. (From a color slide by the author).

passed through the gut of the burrower (possibly worms). This burrow occasionally grades into the small Type II burrow, of which it may be a variation.

Type II Meniscus-filled burrows resembling *Arthrophycus* (Hantzchel, 1975).

Type II burrows occur in two sizes and are most commonly found on both upper and lower bedding surfaces of fossiliferous Kongahu Member beds that are sandwiched between Glasseye Mudstone beds. The smaller-size burrow is 9-17 mm in diameter and averages about 12 mm (Figs. 4/33 and 4/34). The larger burrow is up to 4 cm in diameter, but most average about 2.5-3 cm (Figs. 4/34 and 4/35). Both types may occur together, although the smaller variety is by far the most abundant (Fig. 4/34). Size seems to be the only major difference between them. The smaller burrows are possibly the traces made by juveniles (Fig. 4/34).

The burrows are slightly flattened, branching cylinders with ovoid cross-sections. They follow irregular, curving paths that roughly parallel the bedding planes. The branches have Y-shaped junctions with the main burrows; the base of the junction is often slightly enlarged. Most burrows display an irregular annulation.

The burrow fill is in meniscus-shaped packets, which seem to have their concave side facing the direction of propagation. The fill is usually coarser than the surrounding sediment in the thin beds of coarse Kongahu Member, which are enclosed by mudstone; sandy mud commonly

Figure 4/34 Large and small Type II burrows in Glasseye Mudstone near mouth of Falls Creek. Note small branch (at arrow) suggesting that the small Type II burrows were made by juveniles. Hammer is 30 cm long.

Figure 4/35 Large and small Type II burrows in thin Kongahu Member bed with large mud clasts. Photo taken near mouth of Falls Creek. Head of hammer is 30 cm long.

fills these burrows. The meniscus layers are fairly regularly spaced, usually about 3 mm in the larger burrows and 1.5 mm in the smaller.

The burrows may be traces of arthropods or worms (Hantzschel, 1975) and seem to be feeding traces. The burrows are generally hypichnial ridges, but epichnial ridges, exichnial burrow casts, and endichnial burrows are also common.

Type III Zoophycus

These spreiten structures form large helical cones, which wind around an axis perpendicular to the bedding plane (Fig. 4/36). The cones have a maximum observed basal diameter of 75 cm and are composed of inclined sheets of slightly arcuate lamellae. The apices of the cones always point in the direction of younging of the bed (P. Antun, 1950; among others).

The sheets have an apical angel of about 120° and consist of major and minor lamellae. The major lamellae radiate from the apex in a slight arc and form low resistant ridges on relief specimens. The minor lamellae are poorly preserved, fine, curved lines between the major lamellae. Packed sediment fills the lamellae and cross-sections reveal a regularly spaced, lunate, internal structure.

Zoophycus has only been found in the Glasseye Mudstone. It seems that the problematic Zoophycus producer was discriminate in its choice of feeding substrate. The traces range in age from early Whain-

Figure 4/36 Type III, Zoophycus in broken slab of Glasseye Mudstone from mouth of Little Wanganui River. (1) minor lamellae; (2) major lamella; (3) marginal tunnel. Diameter of lense cap is 55 mm.

garoan at Gentle Annie Point to Duntroonian and probably Waitakian at Little Wanganui Head. Zoophycus-like traces are found in shallow water sediments as well as in deep sea cores taken at 3800 m (Hantzschel, 1970).

Type IV Phycodes(?)

A drawing of Phycodes (Seilacher, 1955), which is pictured in Hantzschel (1975), superficially resembles the very rare lebensspuren encountered at Gentle Annie Point (Fig. 4/37). The trace fossil contains bundles of cylindrical tunnels on the base of a very thin, redeposited, coarse sandy limestone bed. The bundles are preserved as convex hypichnial ridges with a total visible length of 9 cm. The proximal tunnels, about 1 cm in diameter, are unbranched. The distal tunnels divide at acute angles to form two narrow tunnels. The burrows lack external and internal ornamentation.

The example shown in Figure 4/37 is probably a feeding trace. Some (Seilacher, 1955; cited in Hantzschel 1975) consider Phycodes to be a junior synonym for Arthrophycus, a trace fossil resembling those produced by arthropods.

Type V Irregularly branching network of cylindrical burrows

Three dimensional networks of irregularly branching burrows are visible in broken spherical concretions in the Glasseye Mudstone south of Happy Valley Saddle (Fig. 4/38). The unornamented burrows average 2 cm in diameter

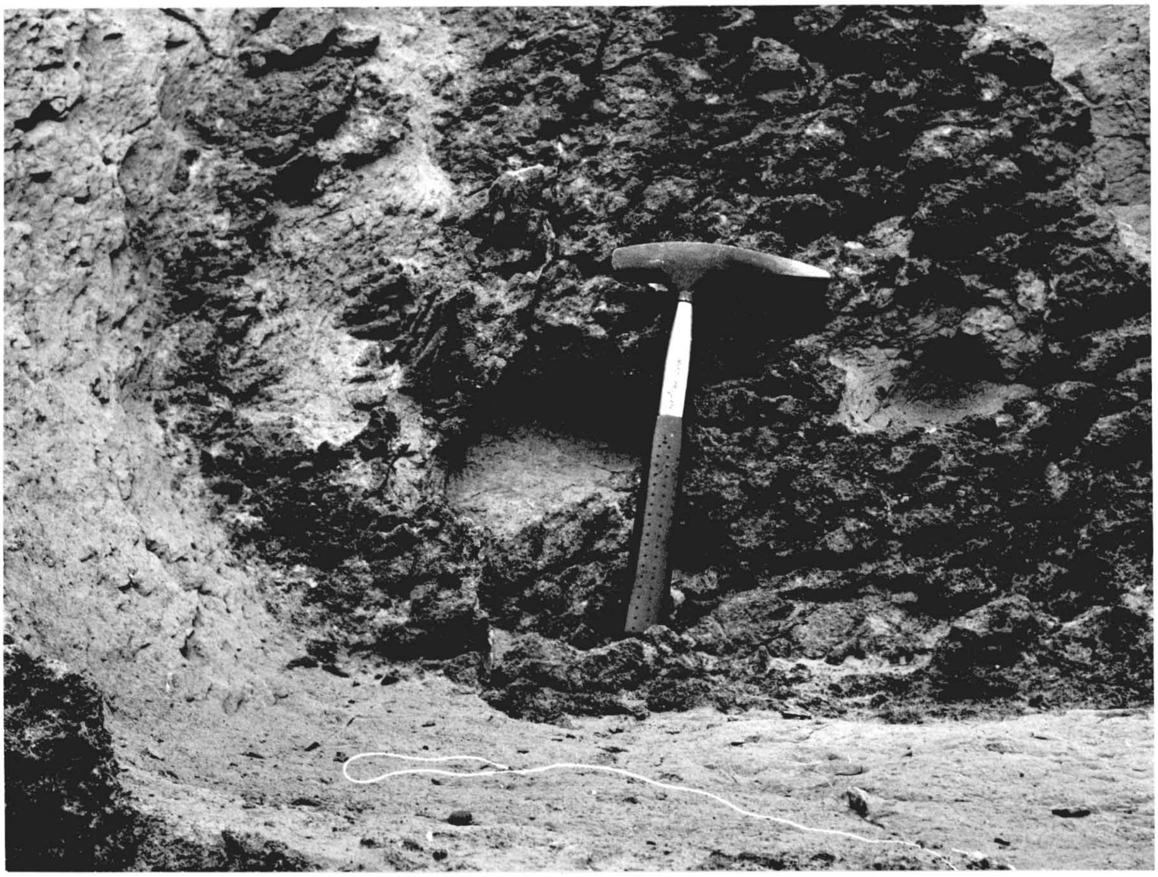


Figure 4/37 Type IV ichnofossil, resembling Phycodes(?); hypichnial ridge on base of overturned Kongahu Member limestone at Gentle Annie Point. Hammer is 33 cm long.

Figure 4/38 Type V burrows visible in broken spherical concretion in Glasseye Mudstone, south of Happy Valley Saddle. Lense cap diameter is 55 mm.

and have Y-shaped bifurcations; the points of branching are not enlarged. The burrow filling is slightly darker, but texturally identical to the surrounding sediment. The color difference results from minute pyrite grains, which are disseminated through the burrow fill. Preservation of the trace fossil does not extend beyond the enclosing concretion.

The ichnofossil has not been positively identified. The description of Thalassinoides in Hantzschel (1975) roughly approximates the aspect of the problematic trace fossil. Thalassinoides, however, is usually smaller, and more regularly branched, often with swellings at the points of branching.

Type VI Small wandering tubes

Clusters of small wandering tubes were seen at several localities in the Glasseye Mudstone (Fig. 4/39). The fodichnial-type trace fossils, about 1 mm thick, are preserved as endichnial burrow casts and are filled with light brown mudstone. The burrows are the traces of sediment-eating animals, possibly worms. The ichnofossil is associated with Planolites(?) in the Glasseye Mudstone at the mouth of Falls Creek.

Type VII Irregular horizontal tunnel network

Figure 4/40 shows a poorly preserved, very rare trace fossil recovered from the Glasseye Mudstone at View Hill. The trace fossil is a ramifying, horizontally branching network of tunnels, which is preserved as

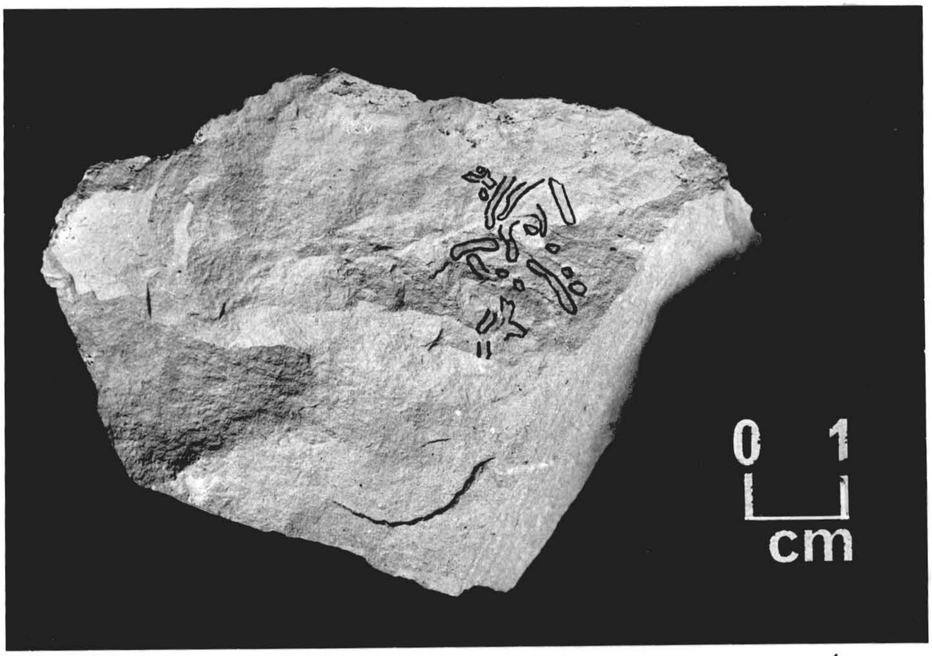


Figure 4/39 Cluster of small wandering tubes (Type VI) in Glasseye Mudstone; tubes are outlined in ink. Scale is in cm. Photo by A. Downing.

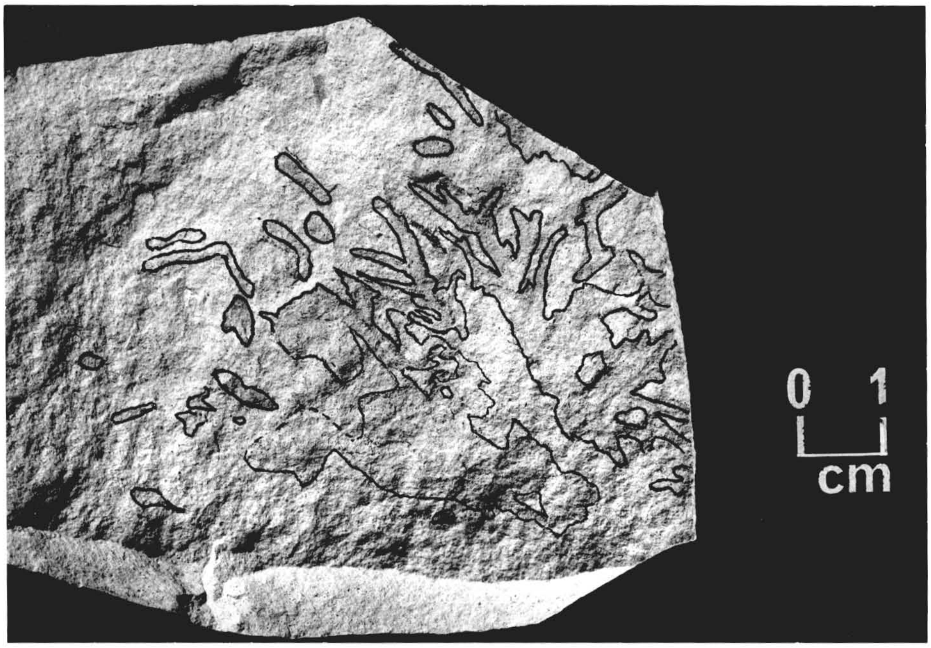


Figure 4/40 Irregular, horizontally branching network of tubes (Type VII) in Glasseye Mudstone from View Hill. Traces are outlined in ink. Scale is in cm. Photo by A. Downing.

endichnial burrow fills. The tunnels average 2 mm in diameter with a maximum length of 45 mm. The branching occurs at irregular intervals and at angles varying from 22° to 63°.

It is possible that the problematic trace fossil is a member of the large and ill-defined ichnogenus *Chondrites*. The trace fossil superficially resembles a drawing of *Chondrites bollensis* (Richter, 1931; pictured in Hantzschel, 1975). The *Chondrites* "form genus" possibly represents the feeding trace of worms.

CHAPTER 5

TEXTURES

TEXTURAL-TREND DIAGRAMS

Maximum grain size vs. stratigraphic position

The maximum grain size versus stratigraphic position was plotted for the Little Wanganui section (Log 7). Measurements of detrital grains in hand specimens, in thin section, and of boulders in the field determined maximum grain sizes. The largest cluster of peaks on the chart corresponds to the position of the major channel fills. The maximum grain size of the Kongahu Member decreases irregularly in the upper 85 m of the Little Wanganui Formation. The mean maximum grain size for 25 Kongahu Member beds in the upper 85 m of Log 7 is 16 mm. The mean maximum clast size for 26 Kongahu Member beds below the upper 85 m of Log 7 is about 6 m. The maximum dimension of Glasseye Mudstone detrital sand grains is 0.14-3.14 mm and averages about 0.55 mm.

C-Mo Diagrams

Modern sedimentologists have often tried to use simply derived grain size parameters to determine the nature of sedimentary environments. Rizzini (1968) reviews the evolution of these attempts. Recently, the C-M diagrams of Passega (1957, 1964, 1972), where C is the coarsest one percentile and M is the median, have been used as a quick method of determining the mode of transport and depositional environment of a sediment. The C-Mo diagram of Rizzini (1968), which equates C with the coarsest one percentile and Mo with the mode, is a variant of the C-M diagram. I attempted to derive the C and Mo data qualitatively from thin sections, hand specimens and outcrop measurements. The C parameter represents the largest detrital clast found on the outcrop or in thin section for mudstone samples. The mode (Mo) comes solely from thin section data. The slide was scanned and several representative grains of the modal class were selected and measured. The results were then averaged. In polymodal samples, only the dominant mode was plotted; however, the coarsest modal size was plotted when polymodal samples exhibited no dominant modes. The inaccuracies in this method are self-evident and are compounded by problems of sampling representability, particularly for samples of bouldery and laterally variable sediments.

C-Mo values for samples from the Kohaihai Limestone, Stony Creek Limestone, and Oparara Member were plotted with the C values on the ordinant and the Mo values on the abscissa. No grouping or discernable trends were visible. Given the inadequate amount of data, the parameters were of little use in distinguishing separate sedimentary environments.

Transparency 1 (lower) on Figure 5/1 shows the C-Mo plots for all samples taken south of the Little Wanganui River, excluding the coastal samples. Circles represent the normal background sediment (Glasseye Mudstone), which

CMo DIAGRAM

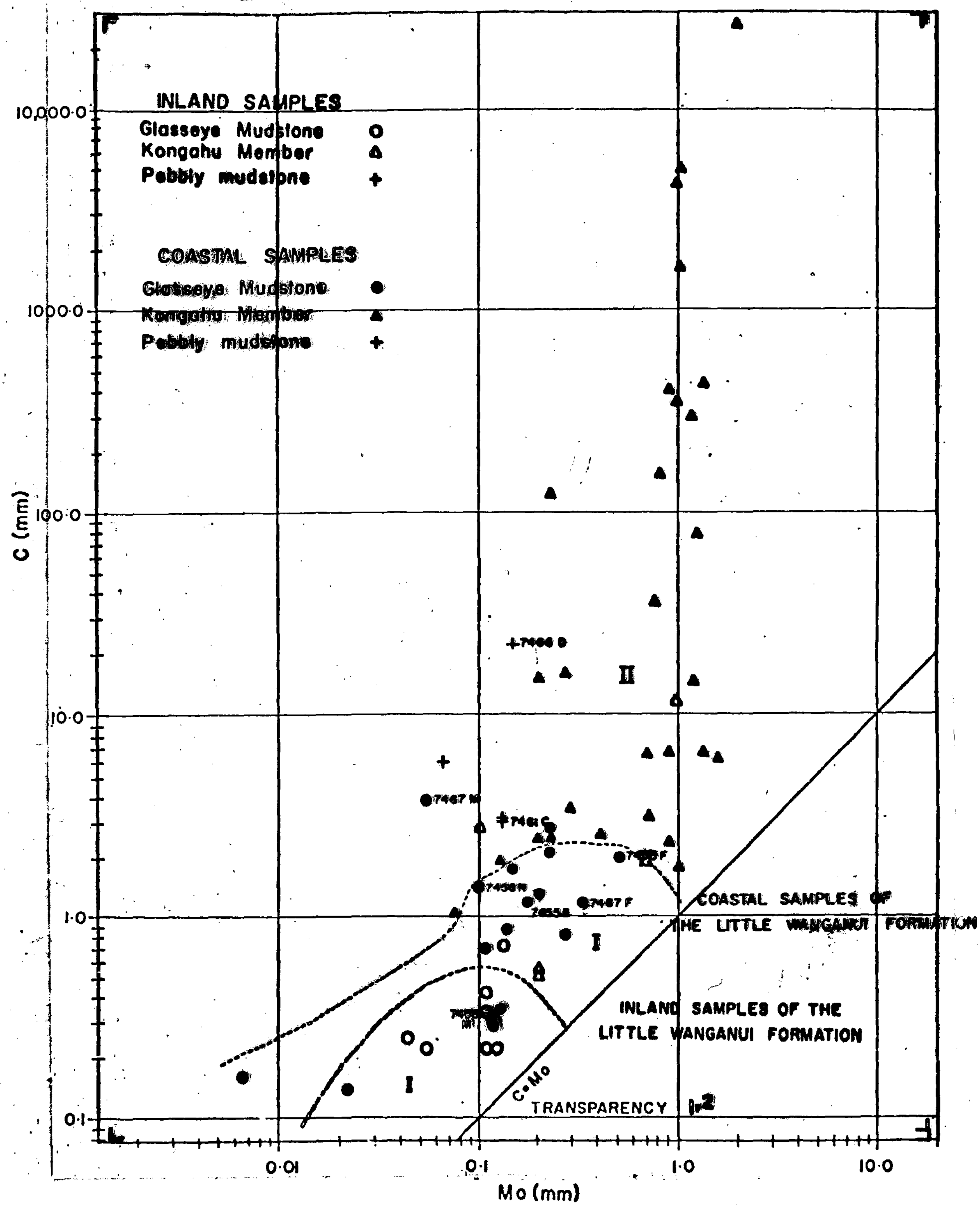


Fig. 5/1

probably accumulated by a slow settling of suspended material. Stars represent pebbly mudstones, and squares represent Kongahu Member sediments (coarse sandy calcarenites and fossiliferous pebbly sandstones), which infrequently occur in the inland section. Two diffuse point clusters are apparent on the transparency. The lower cluster, which is designated as Province I, has the Glasseye Mudstone as its dominant constituent. Kongahu Member samples are the major components of Province II. Samples of highly calcareous Kongahu Member beds, which contain very little detrital material, are found near the province boundary line, as are samples of Glasseye Mudstone, which contain coarse burrow fillings. Province II contains a pebbly mudstone (sample UC 7451 C; note that the Mo value of the pebbly mudstone is well within the Glasseye Mudstone Mo range.

The two previously mentioned provinces are also discernable in the C-Mo diagram (Transparency 2) for samples collected along the coast from Little Wanganui Head to Gentle Annie Point. A finely laminated, calcite-cemented, very fine arenite (sample UC 7458 M) falls within the mudstone group. This fine grained representative of the Kongahu Member may be of distal turbidite(?) origin. Sample UC 7455 B is a burrowed, very muddy, slightly sandy, Kongahu Member calcarenite. Its inclusion in the mudstone province probably reflects an original fine grained composition or chance exclusion of coarse grains in the hand specimen and thin section. The plots that fall within Province II include Kongahu

Member samples, a pebbly mudstone (sample UC 7466 E), and a burrowed mudstone with coarse sand infillings. Burrowed mudstone adjacent to Kongahu Member beds always have anomalously high C values. Biological mixing of the two sediments, unquestionably, causes the high C value. Samples UC 7467 M, 7467 F, 7458 N, and 7455 F are all burrow mixtures. Their Mo values are well within the presumed limits of Province I.

The combined transparencies (Fig. 5/1) show a wide scatter of plots, which primarily results from the vast range of available grain sizes. Inspection of the combined transparencies reveals that the coastal sample mudstone province encompasses coarser sediments than its inland counterpart.

The C-Mo diagrams, using coded data points, show a correlation between clusters (provinces) and inferred depositional mechanism/environment. The crude method of size determination and the limited amount of data resulted in very diffuse overlapping clusters. The C-Mo parameters, as determined in this study, were responsive only to gross variations in depositional mechanisms and environments.

A preliminary study was carried out to determine if different source areas could be distinguished on the basis of roundness. The roundness of a selected size interval of age-equivalent Kongahu Member and Kohaihai Limestone was determined using Power's (1953) visual roundness chart. The Kongahu Member sample contained more angular grains, but the difference was not sufficient to warrant further investigation.

TEXTURAL GROUPS

The four major textural groups that were recognized in the study area are: mudstone; gravelly sandstone (including minor sedimentary breccia and conglomerate); sandstone; and pebbly mudstone. Figure 5/2 illustrates the distribution of the textural groups.

Mudstone

The Glasseye Mudstone represents the mudstone textural group and constitutes most of the Landon sedimentary record in the southern half of the study area. The thickness and wide areal distribution of the mudstone and the concentration of the Kongahu Member in the coastal areas support the contention that the mudstone represents the normal background sediment in the Oligocene basin. Coarse Kongahu Member sediments were sporadically implaced during Landon time. They represent only a small portion of the sedimentary record in this section of the study area.

The mudstone is mainly a calcareous detrital lutite; muddy calcilutite is rare. Very angular to subangular, very fine silt- to very coarse sand-sized grains comprise 5 %-20 % of the sediment. The detrital grains are either concentrated in discontinuous planar laminae or scattered throughout the mudstone. This scattered distribution

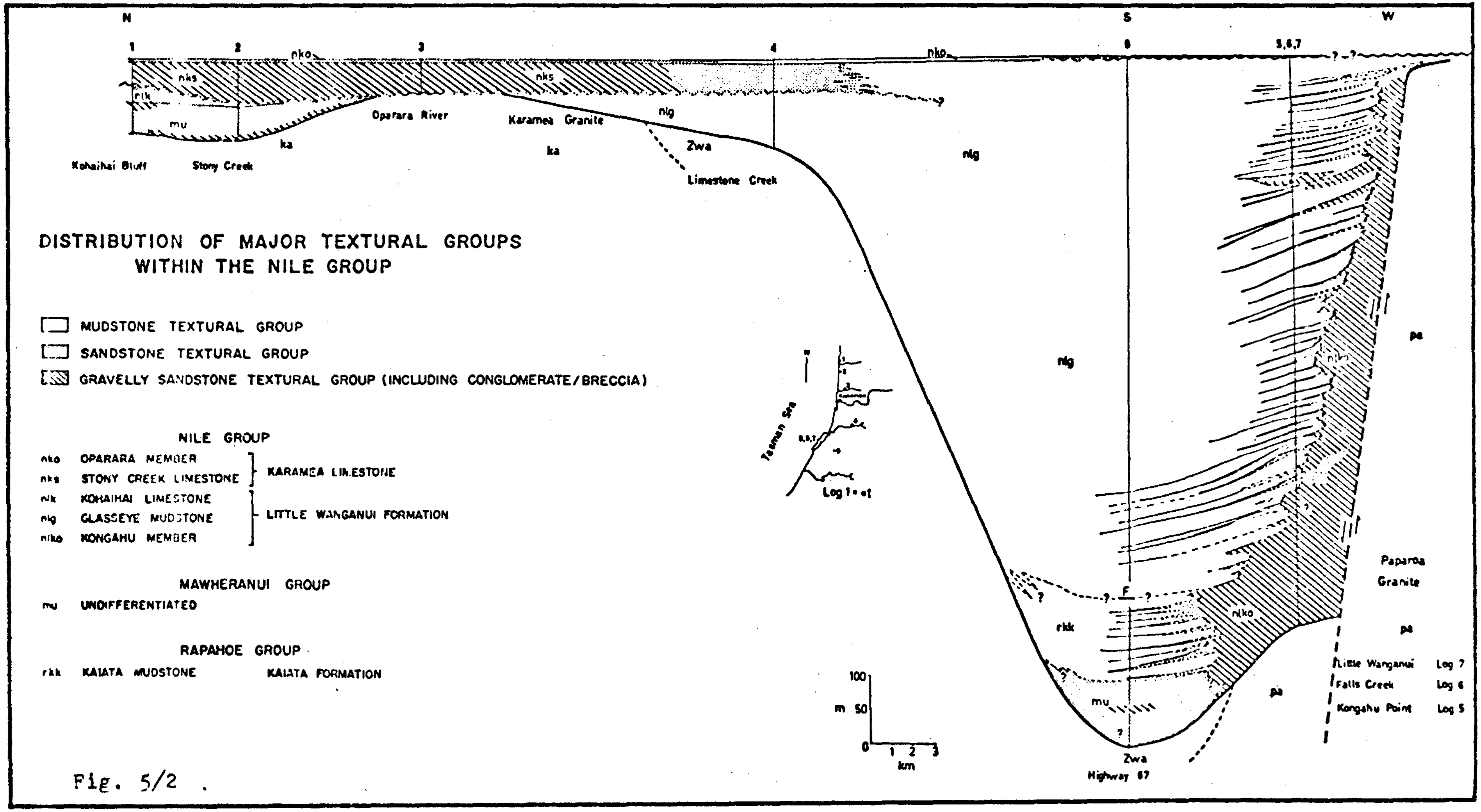

DISTRIBUTION OF MAJOR TEXTURAL GROUPS WITHIN THE NILE GROUP
MUDSTONE TEXTURAL GROUP
SANDSTONE TEXTURAL GROUP
GRAVELLY SANDSTONE TEXTURAL GROUP (INCLUDING CONGLOMERATE/BRECCIA)
NILE GROUP
nko OPARARA MEMBER
nks STONY CREEK LIMESTONE
KARAMEA LIMESTONE
nlk KOHAIHAI LIMESTONE
nlg GLASSEYE MUDSTONE
nlko KONGAHU MEMBER
LITTLE WANGANUI FORMATION
MAWHERANUI GROUP
mu UNDIFFERENTIATED
RAPAHOE GROUP
rkk KAIATA MUDSTONE
KAIATA FORMATION
N
S
W
Kohaihai Bluff
Stony Creek
Oparara River
Karamea Granite
Limestone Creek
Tasman Sea
Log 1-4
Paparoa Granite
Little Wanganui Log 7
Falls Creek Log 6
Kongahu Point Log 5
Zwa
Highway 67
m
km

Fig. 5/2 .

probably reflects extensive burrowing, which destroyed most of the laminae. Burrowed mudstone, which is interlayered with Kongahu Member beds, often contains appreciable amounts of sand. These sediments probably have a bi-modal grain size distribution with the major mode in the clay-size region and the minor mode in the sand-size region.

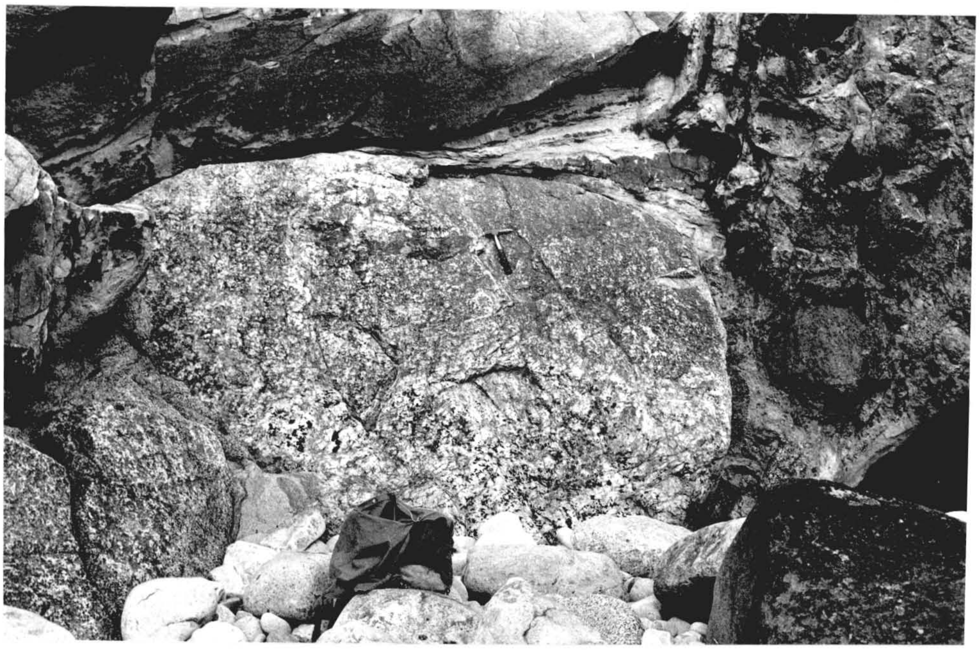
The fine grained nature of the mudstone and the lack of current sorting indicate that quiet water conditions, undisturbed by persistant strong water currents, prevailed during deposition.

Gravelly Sandstone

The gravelly sandstone textural group includes all Nile Group sediments in which 5 % or more of the fragments are larger than 2 mm. Figure 5/2 shows the distribution of this textural group. The majority of the sediments in this textural group appear in the Kongahu Member along the coast between the Little Wanganui and Mokihinui Rivers.

In thin section, as well as in the field, the gravelly sandstone appears to be very poorly sorted and polymodal. Modes are present in the boulder-, pebble-, very coarse to coarse sand-, and mud-size ranges (Fig. 5/1). The Kongahu Member contains granite boulders up to 11.5 m long (Fig. 5/3), but most of the boulders are in the 0.3-0.5 m range. Boulders in the lowest horizons at Kongahu Point are highly angular to subangular; whereas, those in the Whaingaroan to late Duntroonian deposits are subangular to subrounded.

Figure 5/3 Very large granite boulder, 4.2 m in diameter, in very poorly sorted, very coarse sandy, medium bouldery conglomerate (Kongahu Member). The sediment to the right of the very large boulder is polymodal; with modes in the boulder-, cobble-, coarse pebble-, very coarse sand-, and mud(?)-size ranges. Note that the very large boulder protrudes into the overlying sediment. Photo taken on coast south of Little Wanganui Head at S18/503164. Length of hammer is 33 cm.



The majority of the large clasts in the gravelly sandstones are matrix-supported, and "float" in a matrix of coarse sand, bioclastic debris and mud. Distribution of the granite and gneiss clasts throughout the matrix is commonly random. Large clasts from the upper portion of a bed may protrude into the overlying sediment (e.g., Fig. 5/3). Some clasts seem disproportionately large in comparison to the thickness of the enclosing bed (e.g., Fig. 5/4). Clusters of granite boulders with little matrix (i.e., clast-supported) occur near the base of the Kongahu Member at Kongahu Point and Gentle Annie Point and fill a few of the larger channel structures near Little Wanganui Head.

Sample UC 7457 B from the contact zone between the Kongahu Member and Paparoa Granite at Kongahu Point exhibits an interesting microtexture (Fig. 5/5). The sediment consists of small boulders, cobbles and pebbles in a highly micaceous matrix of very coarse sand and silt. The fine-grained constituents (silt-sized quartz and feldspar particles) often have diffuse coatings of muscovite and biotite (Fig. 5/6). Under the binocular microscope, the pale greenish-grey coatings show an earthy, uneven outer surface. These micaceous coatings resemble cutans, which are common pedalogical features (Teruggi and Andreis, 1971). Cutans (clay skins) " ... occur on the surfaces of grains in relatively densely packed plasma; displacement of the grains reveals cutanic material either adhering to the grains or on the surfaces of the impression left by its removal. The

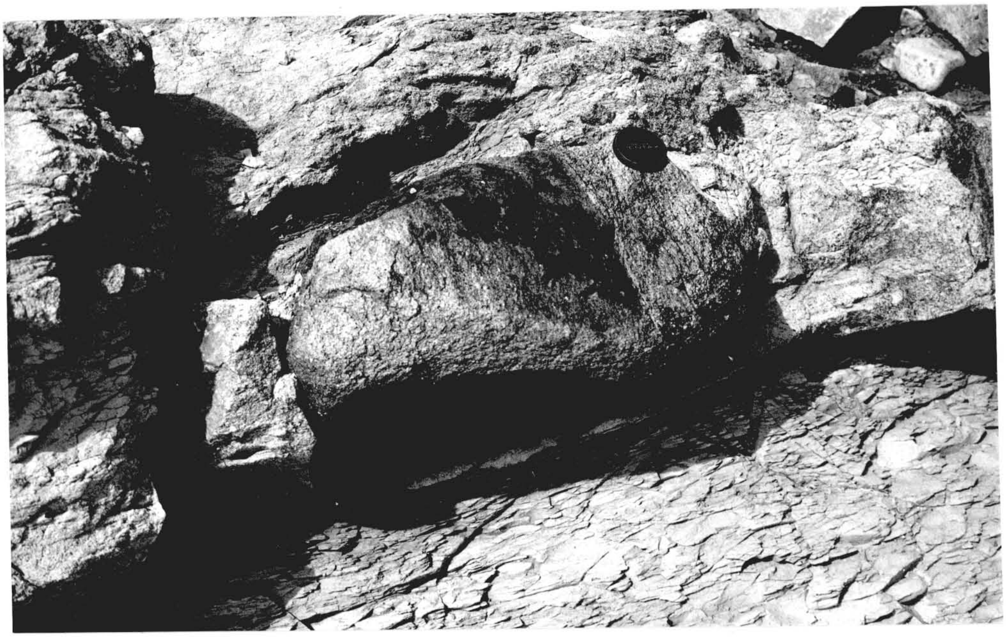


Figure 5/4 Subrounded small granite boulder in muddy, very coarse sandy limestone (Kongahu Member). Boulder protrudes into overlying sandy Glasseye Mudstone. Photo taken near Little Wanganui Head at S18/505166. Diameter of lense cap is 55 mm.

Figure 5/5 Contact between Kongahu Member and Paparoa Granite at Kongahu Point (S18/434101). Granite crops out 4 m to right of Ewan Fordyce. Ewan points to area where the sample containing cutanic structures was taken (sample UC 7457 B).

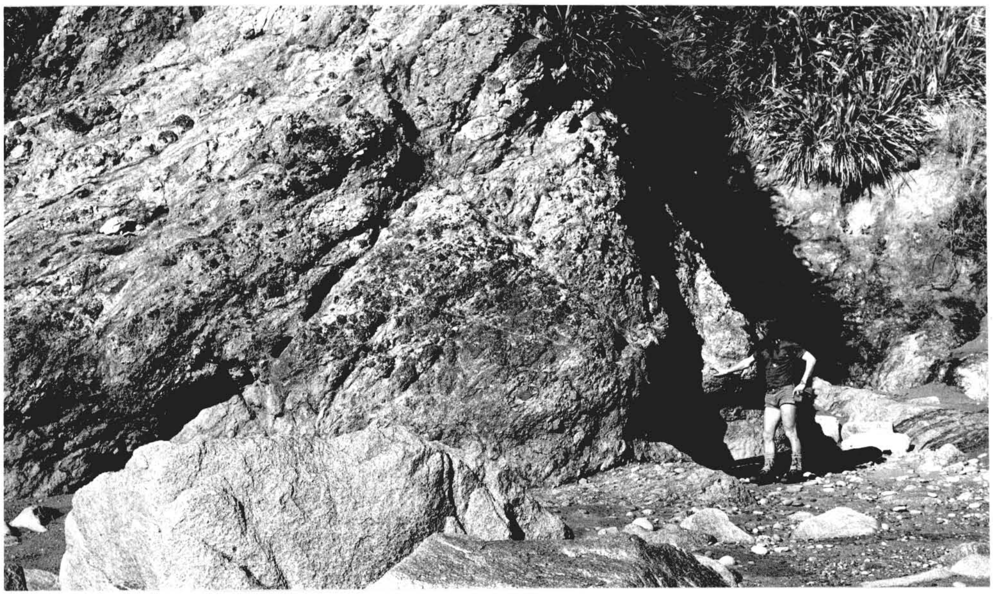
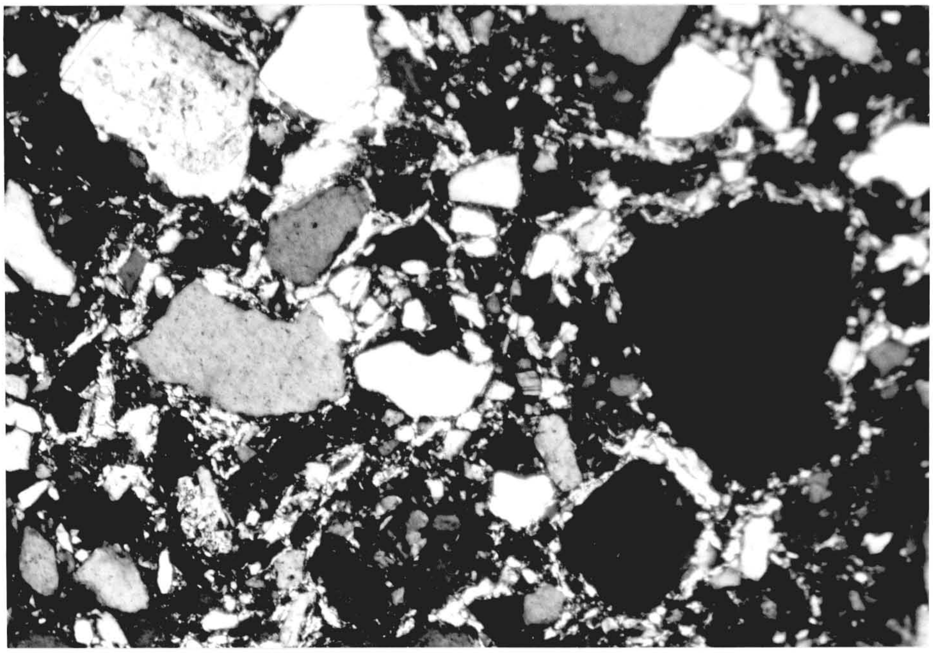


Figure 5/6 Photomicrograph of sample UC 7457 B showing cutanic microtexture. Cutans of muscovite (and minor biotite) surround small grains of quartz, microcline, and plagioclase. Crossed nicols; field of view is 690 μ.



cutans are not visibly ... connected to voids which could act as conducting channels" (Brewer, 1964, p. 209). It has not been established that cutans are exclusively pedogenic (Teruggi and Andreis, 1971), but their presence does merit consideration of a soil affinity for the rock.

The extreme clast size, very poor sorting, and low degree of roundness in the Kongahu Member gravelly sandstone imply that some high-energy mechanism emplaced the gravelly sandstones. The range of clast sizes and the lack of sorting suggest that the sediment was not water-laid and that the environment of deposition was not subjected to strong water currents. The presence of very large boulders implies that the source area had considerable relief and was probably near by.

The Stony Creek Limestone at Kohaihai Bluff (a molluscan biomicrudite) also falls in the gravelly sandstone textural group. A textural inversion exists at the base of this sediment, where a micrite matrix binds large mollusc fragments and subrounded quartz pebbles (3 mm in diameter). Energy conditions were probably high throughout much of the region covered by the Stony Creek Limestone (see below). The muddy Stony Creek Limestone at Kohaihai Bluff represents a local area of low energy; or perhaps, a mud bank stabilized by marine vegetation (such as <u>Thallassia</u>).

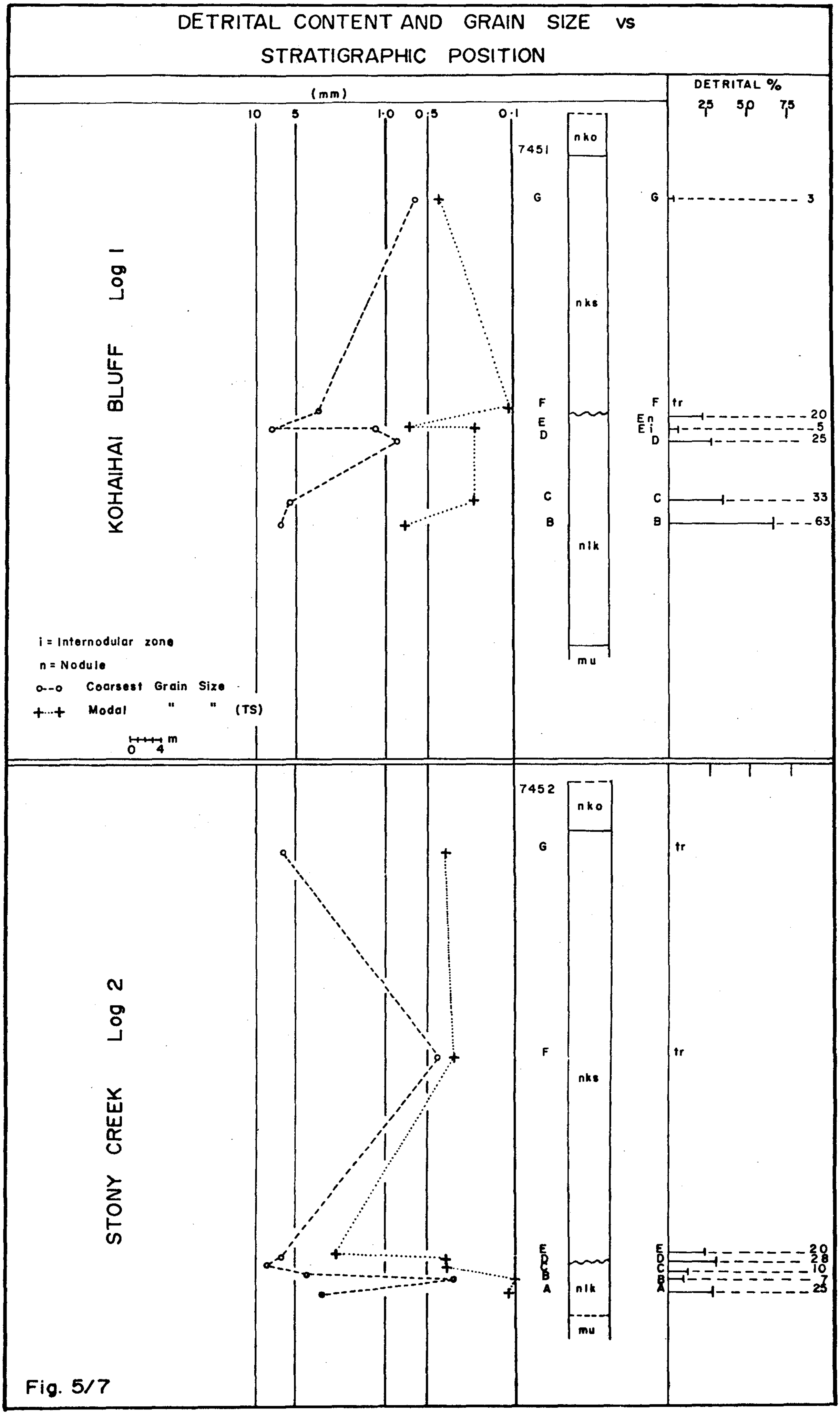
The upper part of the Oparara Member at Happy Valley Saddle consists of a fossiliferous, bimodal fine pebble and very coarse sand, foraminiferal bryozoan biosparite. Sorting within the modes is moderate and roundness of detrital grains ranges from angular to well rounded. The roundness of the detrital grains, the presence of pebbles, and the absence of mud suggest that the upper Oparara Member at Happy Valley Saddle was deposited in a high energy environment. Lower energy conditions existed farther to the north where muddy calcarenite and fine sandstone were deposited.

Sandstone

Sandstones occur throughout the Kongahu Member and are interbedded with conglomerates. The sandstones (as calcarenites) comprise the majority of the Kongahu Member in the upper 85 m of the Little Wanganui Formation. Sorting of sandstones is generally very poor. Polymodal grain size distribution is common; poorly sorted modes occur in the very coarse sand- and mud-size ranges. The sand grains are mainly angular but vary from very angular to subrounded. Most of the sediments are mud- (matrix-) supported. Clast-supported textures commonly occur near Kongahu Point and infrequently appear in the major channel fills near Little Wanganui. An overall vertical decrease in detrital content is evident in the sparse Kongahu Member beds of late Whaingaroan to Waitakian age, which are exposed along the Little Wanganui River. There is some indication that the maximum grain size also decreases with declining detrital content (see above).

Most of the Kohaihai Limestone, Stony Creek Limestone, and sediments of the Oparara Member fall within the sandstone textural group (with the exceptions noted above under Gravelly Sandstone). Several textural trends are evident in the Nile Group sediments that crop out in the Karamea area. Sorting improves towards the top of Kohaihai Limestone at Kohaihai Bluff and Stony Creek (Fig. 5/7), and the mud content and maximum and modal grain sizes decrease concommittantly. The modal and coarsest grain sizes increase sharply at a local unconformity, which marks the top of the Kohaihai Limestone; they then appear to decrease up through the Stony Creek Limestone. Sorting improves and carbonate percentage increases upwards through the Kohaihai Limestone, which grades from a moderately sorted sandstone to a well sorted calcarenite. Sorting decreases above the local unconformity, then increases again in the Stony Creek Limestone. The Stony Creek Limestone is generally a well washed bryozoan biosparite to biosparudite. The Oparara Member is a muddy very fine sandstone at Kohaihai Bluff and Stony Creek, a well washed biosparite at Oparara, and a very fine sandy biomicrite at Limestone Creek.

The high mud content and poor sorting of the lowest Kohaihai Limestone suggest that the sediment accumulated under low energy conditions. Higher energy depositional conditions, capable of winnowing, prevailed during the deposition of the upper Kohaihai Limestone.


DETRITAL CONTENT AND GRAIN SIZE vs
STRATIGRAPHIC POSITION
(mm)
10
5
1·0
0·5
0·1
DETRITAL %
25
50
75
KOHAIHAI BLUFF Log 1
7451
nko
nks
nlk
mu
G
F
E
D
C
B
En
Ei
tr
3
20
5
25
33
63
i = Internodular zone
n = Nodule
Coarsest Grain Size
Modal " " (TS)
m
0 4
STONY CREEK Log 2
7452
A
10
7
28
Fig. 5/7

The increase in maximum and modal grain size above the late Duntroonian unconformity and the general mud-free nature of the sediment suggest a moderate to high energy (winnowing) depositional environment for the Stony Creek Limestone. The presence of mud and the fine grain size imply that low energy depositional conditions prevailed at Kohaihai Bluff, Stony Creek, and Limestone Creek while the Oparara Member accumulated; the absence of mud in the Oparara Member at Oparara suggests moderate energy depositional conditions.

Pebbly Mudstone

Pebbly mudstone is a rare textural group found only in the Little Wanganui Formation south of the Little Wanganui River (Fig. 5/8). The sediment consists of small pebbles to large granite cobbles, which are suspended in a matrix of slightly sandy, calcareous detrital lutite (Glasseye Mudstone). Large fossil fragments are often mixed with the pebbles. Pebbly mudstones commonly overlie slump planes south of Little Wanganui Head.

Figure 5/8 Valves of the giant brachiopod, Liothyrella magna, in a thin band of pebbly mudstone. Pebbles up to 4 cm occur with the fossils. Little Wanganui coast near S18/498158. Length of hammer is 30 cm.

CHAPTER 6

COMPOSITION

COMPOSITION DIAGRAMS

DAM triangles

DAM triangles emphasize the difference in composition between members of the Nile Group. 'D' represents detrital grains; 'A' represents allochems; and 'M' represents mud (which includes detrital and carbonate mud as well as carbonate cement). The component percentages were estimated from thin sections with the aid of a visual, percentage-comparison chart. Appendix I discusses the reliability of these estimates.

DAM plots for the Kohaihai and Stony Creek Limestones and the Oparara Member (Fig. 6/1a) indicate that most of the samples contain over 50 % bioclastic allochems. Otherwise, the samples within each member show considerable compositional variation.

Figure 6/1b presents the DAM plots for the Kongahu Member and Glasseye Mudstone. Inland and coastal samples from each member were distinguished in the hope of obtaining data concerning the direction of sediment supply. The Kongahu Member samples show a wide compositional scatter, and most contain less than 60 % matrix. The irregularly dashed line separates the majority of Kongahu Member and Glasseye Mudstone samples. The Glasseye Mudstone generally contains less than 15 % detrital

DAM TRIANGLES

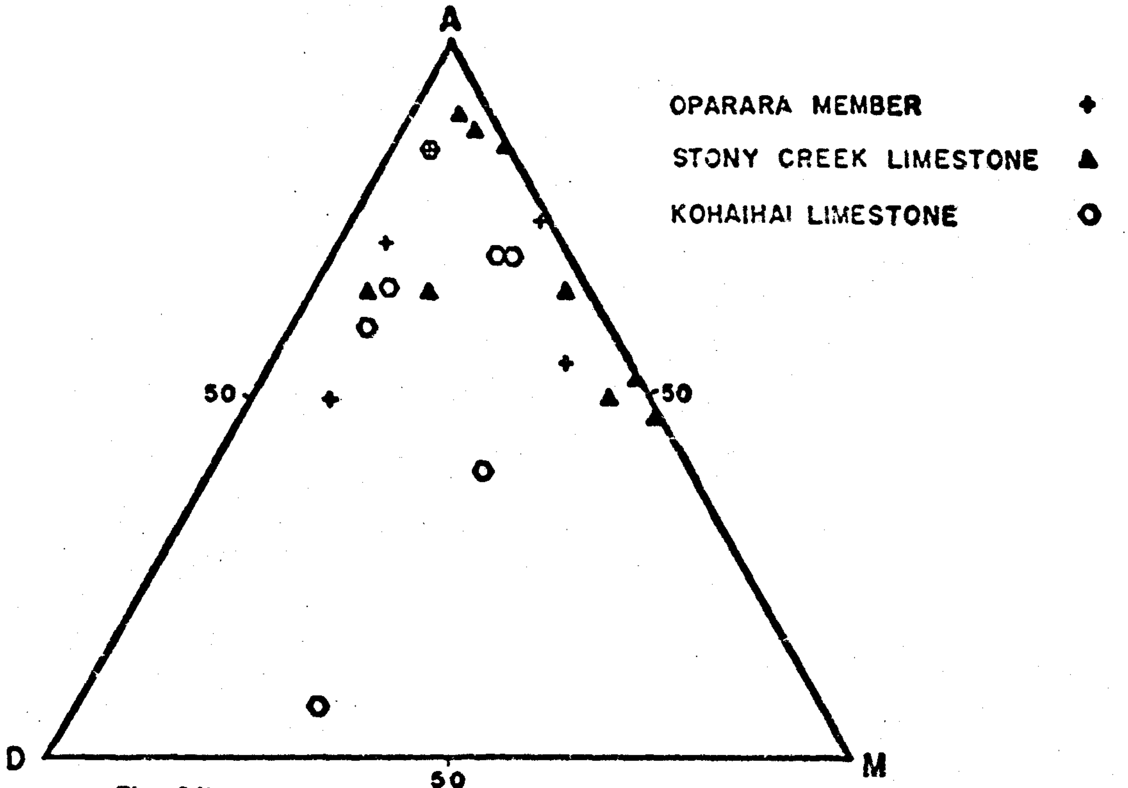


Fig. 6/1a

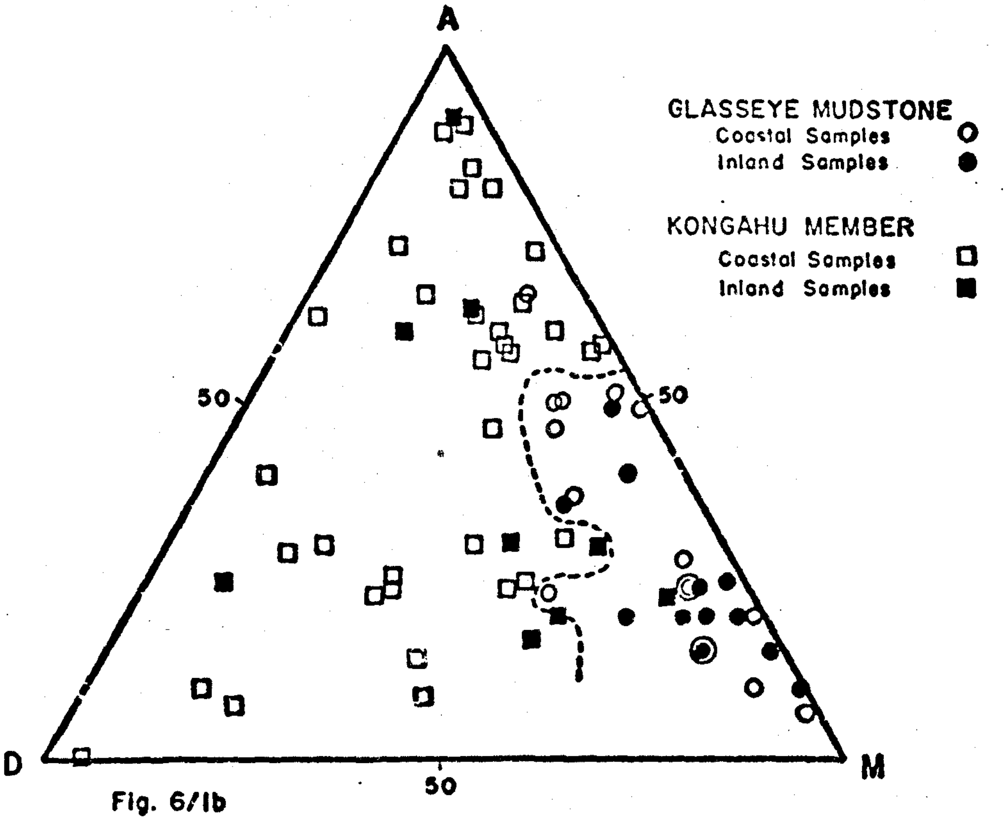


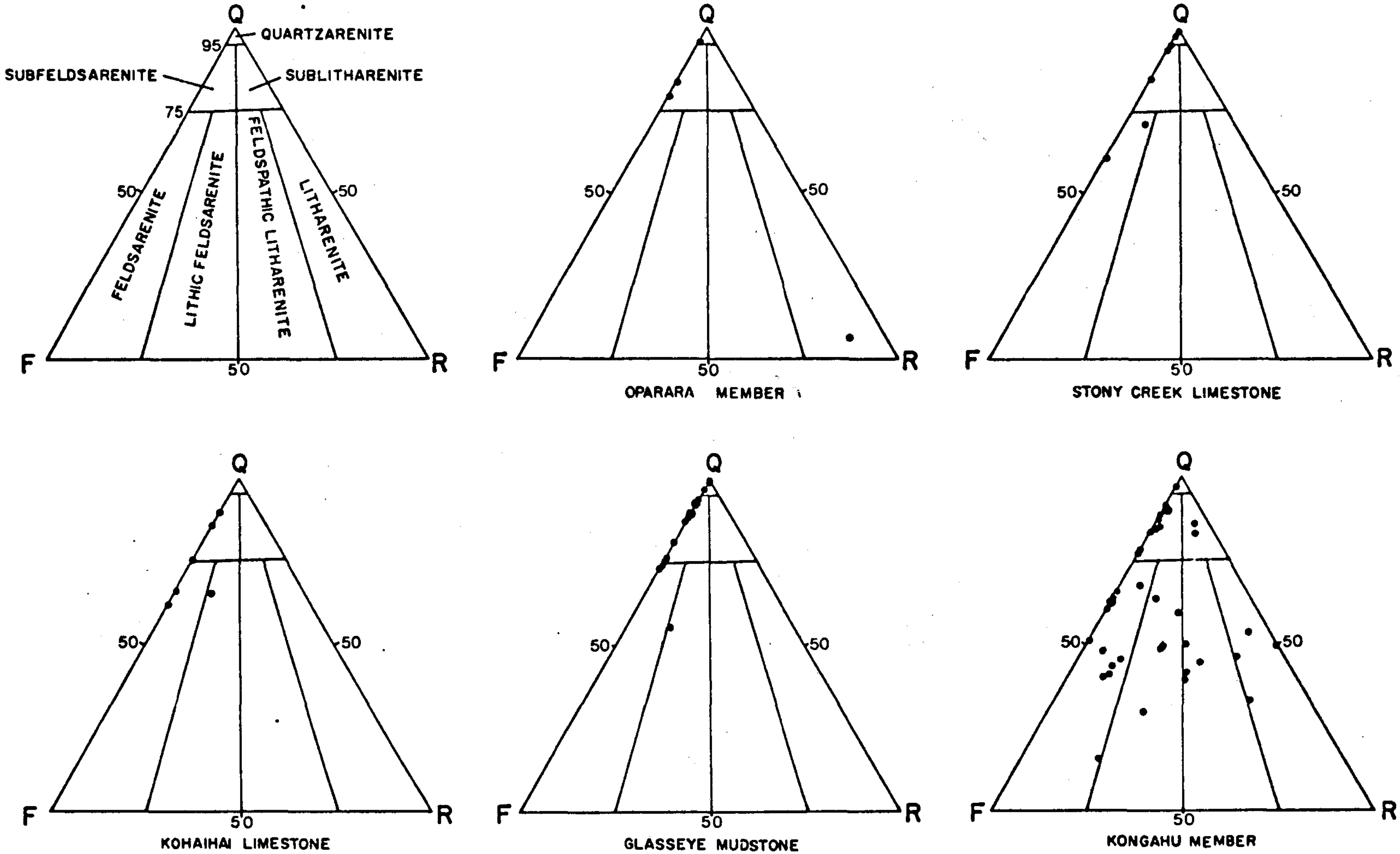
Fig. 6/1b

grains, 7 %-65 % allochems, and 27 %-92 % mud. Samples from the inland outcrops have a lower percentage of allochems than do the coastal samples and cluster near the mud pole.

QFR triangles

Figure 6/2 plots, on the QFR triangle of Folk, Andrews, and Lewis (1970), the percentage of sand-size quartz, feldspar, and rock fragments in the thin sections (see App. I for data concerning the reliability of these estimates). The detrital portion of the Kohaihai Limestone consists mainly of quartz and feldspar; the majority of the samples cluster within the subfeldsarenite and feldsarenite divisions. The Stony Creek Limestone detritus clusters in the quartzarenite-subfeldsarenite range, although the detrital fraction of the lowest Stony Creek Limestone samples from the type locality is a feldsarenite. The detrital composition of the Oparara Member samples is mostly quartzarenite to subfeldsarenite. The sample from Happy Valley Saddle, which contained numerous granite and gneiss rock fragments, is a plutonic litharenite (plutarenite). The identifiable detrital fraction of the Glasseye Mudstone falls largely into the quartzarenite to subfeldsarenite classes. The Kongahu Member samples show a wide scatter, in keeping with the variable nature of the member. All of the compositional classes are represented, but over 50 % of the samples fall within the subfeldsarenite and lithic feldsarenite groups.

QFR TRIANGLES



REFERENCE : FOLK, ANDREWS, and LEWIS, 1970

FIG. 6/2

DETRITAL MINERALOGY

Table 6/1 outlines the percentages of the main detrital components that are identifiable in thin section.

Quartz is the dominant detrital mineral throughout the Nile Group. Very angular to subangular, very coarse to very fine sand-sized quartz grains predominate in the Kongahu Member. The grains frequently contain vacuoles and inclusions of rutile or tourmaline. Most of the grains are monocrystalline and have straight to slightly undulose extinctions. The quartz grains in the Glasseye Mudstone are angular to subangular and vary widely in size. Subrounded to very well rounded, medium to fine sand-sized quartz grains are common in the Kohaihai Limestone. The Stony Creek Limestone contains angular to rounded quartz grains, ranging in size from fine pebbles to fine sand. The Oparara Member at Kohaihai Bluff and Stony Creek consists mainly of angular to subrounded, fine to very fine quartz sand. The member contains much less quartz near Happy Valley Saddle, where subrounded to rounded, very fine pebbles and very coarse sand-sized grains of quartz are mixed with granite and gneiss rock fragments.

Microcline is present in all rock units. The mineral commonly occurs as fresh, fine to very coarse sand-sized grains, which are commonly replaced by calcite.

TABLE 6/1 Major Detrital Components of Nile Group Sediments

Percentages based on thin-section estimates.

Member	Detrital Content (Range) Mean	Quartz $\frac{100\ (Q)}{Q+F+R}$	Microcline $\frac{100\ (M)}{Q+F+R}$	Orthoclase & Untwinned Plagioclase $\frac{100\ (A)}{Q+F+R}$	Plagioclase $\frac{100\ (P)}{Q+F+R}$	Altered Feldspar $\frac{100\ (A)}{Q+F+R}$	Rock Fragments $\frac{100\ (R)}{Q+F+R}$
Oparara Member	(1-40) 21	(4-96) 66	(3-11) 6	(1-13) 6	(0- 2) 1	(0- 5) 2	(0-85) 21
Stony Creek Limestone	(1-28) 10	(61-99) 87	(0-19) 9	(0- 6) 1	(0- 2) 1	(0- 6) 2	(0- 5) 1
Kohaihai Limestone	(7-63) 30	(65-89) 75	(1-19) 9	(3-20) 10	(0- 3) 1	(1- 7) 3	(0-10) 2
Glasseye Mudstone	(1-25) 8	(57-97) 85	(0-25) 6	(0- 7) 3	(0- 4) 1	(0-10) 2	(0-10) 1
Kongahu Member	(1-95) 26	(16-98) 63	(0-55) 15	(0-43) 7	(0- 7) 2	(0- 9) 1	(0-50) 13

Calcitization usually occurs as irregular patches within the grain. Microcline grains often contain small inclusions of quartz and orthoclase. Fine pebbles of microcline are common in the Lower Kohaihai and Stony Creek Limestones and in the Kongahu Member.

Orthoclase and untwinned plagioclase feldspars are common throughout the area, particularly in the lower Kohaihai Limestone and the Kongahu Member. The mineral is particularly abundant in the Kongahu Member samples from Gentle Annie Point, which contain large amounts of gneiss detritus. Orthoclase grains are usually angular, fine to medium sand-sized; vacuoles, sericite, and other clay minerals often cloud the grains. Irregular patches of calcite replace some of the grains, especially along cleavages and fractures.

Plagioclase is a minor detrital constituent of the rocks. It is found mainly in the Kongahu Member and Kohaihai Limestone. The mineral is often replaced by calcite and is commonly vacuolized. Seritization is rare. Inclusions of quartz and mica frequently occur.

Most samples contain altered feldspars, which cannot be positively assigned to any feldspar group. This type of feldspar is most common in the lower Kohaihai Limestone, which overlies the undifferentiated Mawheranui Group.

Muscovite and biotite are the dominant micas present. Muscovite is ubiquitous but is most common in the Kongahu Member, particularly at Kongahu Point. Musc ite flakes contain small inclusions of quartz and feldspar. Several muscovite flakes from Kongahu Member samples (App. IV) contain peculiar corkscrew-shaped inclusions. This type of inclusion may be diagnostic of a specific source rock/area. The inclusions have not been previously recorded. Biotite is widespread, but is less common than muscovite. The biotite flakes contain numerous inclusions of tiny zircon crystals with pleochroic haloes. Traces of chlorite occur in Kongahu Member beds from the Little Wanganui Head area. The mineral was not detected elsewhere.

Table 6/2 presents the data from a preliminary x-ray diffraction study, which was used to determine the clay mineralogy of the Glasseye Mudstone. The study included samples from both inland and coastal exposures. Montmorillonite and illite are the dominant clay minerals. Small amounts of kaolinite are present in most samples. The clay mineralogy does not vary substantially between the inland and coastal exposures and no definite vertical trends were noted.

The x-ray diffraction patterns showed a broad bulge between 2.9 and 4.8 Å, which was attributed to amorphous silica that was contained in siliceous sponge spicules and radiolaria. Disordered cristobalite was also detected in several of the samples (Chap. 7, and Fig. 7/10).

TABLE 6/2 CLAY MINERALOGY OF THE GLASSEYE MUDSTONE

Sample No.	Location Index	Clay Mineralogy
7467 T	Log 7, S18/512164	M, I, minor K
7466 L	Log 7, S18/505166	M, I, minor K
7467 'O'	Log 7, S18/502163	M, I
7455 C	Log 8, S18/409029	M, I
7464 C	Log 9, S18/553094	M-C, I, minor K
7463 A	Log 9, S18/536081	M, I
7461 'O'	Log10, S18/477012	M, I, minor K

M=Montmorillonite, M-C=mixed layer Montmorillonite-Chlorite, I=Illite, K=Kaolinite

Minor amounts of accessory minerals, including tourmaline, zircon, magnetite-ilmenite, and leucoxene, occur in the Nile Group. Tourmaline is the dominant accessory mineral. It is found as pleochroic, pale green to dark brown, angular, fine sand-sized particles. Fist-sized sprays of black, radiating, acicular tourmaline crystals are found in some of the larger granite boulders near Little Wanganui Head; the fine fragments in the sediment probably derive from similar sprays. Zircon is less common in thin section than tourmaline and usually appears as colorless, very small euhedral or subhedral crystals. Ilmenite that is partly replaced by leucoxene is rarely encountered in thin section.

Small amounts of granitic rock fragments are found in the Stony Creek and Kohaihai Limestones. The Kohaihai Limestone contains about 1 % near its base, but only traces are found in the upper part of the member. The lower Stony Creek Limestone contains about 6 % granite rock fragments, but this amount decreases substantially in the upper portion of the member. No rock fragments are apparent in the Oparara Member in the Karamea region; however, about 85 % of the detrital fraction at Happy Valley Saddle (Log 9) is composed of granite and gneiss rock fragments. The gneiss fragments consist mainly of quartz and plagioclase with minor muscovite and biotite.

Rock fragments comprise up to 50 % of the detrital fraction of the Kongahu Member. Granite is the dominant rock type between Little Wanganui and Kongahu Point. The granite consists mainly of quartz and microcline with lesser amounts of plagioclase, orthoclase, muscovite, and biotite. At Gentle Annie Point, the Kongahu Member contains abundant gneiss rock fragments, which are very angular to subangular and vary in size from very coarse sand to very large boulders. The gneiss consists of dark brown biotite, quartz, and plagioclase. Vacuoles and sericite generally alter the plagioclase. The Glasseye Mudstone contains minor angular to subangular, medium to very coarse sand-sized granite fragments between Kongahu Point and Little Wanganui Head; gneiss fragments are present in the mudstone near Gentle Annie Point. The Paparoa Granite, which is gneissic at Three Mile Creek and Gentle Annie Point, is probably the source of the granite and gneiss rock fragments.

CARBONATE COMPONENTS

Skeletal carbonate allochems

Tables 6/3-6/7 present the identified skeletal elements and a brief summary of their paleoecological significance for each Nile Group member.

Bryozoa are major allochem constituents in the Nile Group sediments. Table 6/8 outlines the distribution of bryozoa. Bryozoa are minor components of

TABLE 6/3 Fauna and Flora of the KOHAIHAI LIMESTONE

All are widespread unless otherwise indicated. a=abundant, vc=very common, c=common, s=sparce, r=rare

Macrofossils	Occurrence	Preservation	Ecology
Brachiopods	c	fragmented, some whole	epifaunal, low level filter feeders
Bivalves _Ostrea_ _Chlamys_ cf. _williamsoni_	r; Kohaihai Bluff	as above	attached epifaunal suspension feeders
Lentipecten _Serripecten_	s	mostly broken, disarticulated valves	free swimming epi- to semi-infaunal suspension feeders
Pleuromeris	r; Kohaihai Bluff	whole	semi-infaunal deposit feeder; recent species found in tidal channel gravels
Gastropods _Architectonica_	s	mostly fragmented	grazer ?
Echinoderms	a	usually fragmented	semi-infaunal to infaunal deposit feeder
Crinoids	r; Stony Creek	columnal segments only	attached, epifaunal, high level filter feeder
Bryozoa encrusting forms branching forms	c	usually fragmented	epibenthic encrusting carnivores; recent species favor shallow shelf waters 20-80 m deep
Solitary corals	r; Kohaihai Bluff	whole	attached epibenthic carnivore

Vertebrates fish teeth	r; Kohaihai Bluff	whole	nektonic
MICROFOSSILS Benthonic foraminifera	a	whole, many bored and(or) micritized	variety of benthonic niches
Planktonic foraminifera	c	whole	planktonic
Red algae	s	fragmented	encrusting epiflora

Sources for ecologic data on Tables to : Milliman, 1974; Morton and Miller, 1968; Tasch, 1973; Ward, 1973. Brachiopod and mollusk identification from N. Z. Fossil Record Forms S12f/500-502.

TABLE 6/4 Fauna and Flora of the GLASSEYE MUDSTONE

All are widespread unless otherwise indicated. a=abundant, vc=very common, c=common, s=sparse, r=rare

MACROFOSSILS	Occurrence	Preservation	Ecology
Brachiopods	vs	mainly single, whole or broken valves	attached epifaunal filter feeders
Mollusc	s	mostly fragmented, a few whole; many are bored	epi- to semi-infaunal suspension feeders; pectens free swimming suspension feeders
Echinoderms	s-c	mostly plates, spines; some whole spatangoid echinoids	mainly semi- to infaunal deposit feeders
Cetacean bones	r	intact and fragmented bones up to 60 cm long	nektonic
Fish teeth, bones	r	usually whole	variety of benthonic niches
MICROFOSSILS			
Benthonic foraminifera	c	usually whole	variety of benthonic niches
Planktonic foraminifera	a	mostly whole	planktonic
Sponge spicules	c	mostly siliceous sponge spicules; monaxons and triradials; often replaced by calcite	epibenthic filter feeders
Red algae	s; mostly along coast	small fragments	epibenthic encrusting flora

Ostracods	s	disarticulated valves; usually whole	benthonic or nektonic omnivores
Bryozoa small branching cylinder or sticks fenestrate	s; c near burrowed Kongahu Member beds	fragmented zoaria	epibenthonic attached carnivores
Plant detritus	s-c	finely comminuted debris, some whole leaves	land-derived flora

TABLE 6/5 Fauna and Flora of the KONGAHU MEMBER

All are widespread unless otherwise indicated. a=abundant, vc=very common, c=common, s=sparse, r=rare

MACROFOSSILS	Occurrence	Preservation	Ecology
Brachiopods *Liothyrella magna*	r: found south of Little Wanganui Head	mostly whole, disarticulated valves	attached epifaunal filter feeders
Bivalves *Acesta* cf. *regia, imitata* *Ostrea* cf. *wollastoni*	s	mostly fragmented; a few whole valves	attached epifaunal suspension feeders
Pectens *Mesopeplum burnetti*	s	mostly fragmented; a few whole but disarticulated valves	free swimming epi- to semi-infaunal suspension feeders
Bryozoa encrusting branching fenestrate	c-a	fragments, and some nearly complete colonies up to 7 cm long.	encrusting epifaunal filter feeders
Echinoderms	s-vc	plates and spines only	mostly semi-infaunal deposit feeders
Red algae	s-vc	mostly fragments; some complete rhodoliths	epibenthonic encrusting flora
MICROFOSSILS			
Pelagic foraminifera	s-c	mostly whole	planktonic

Benthonic foraminifera	vc-a	mostly whole; some bored; a few replaced by chalcedony	variety of benthonic niches
Sponge spicules	r-c most common in muddy samples	whole and broken monaxons and triradiates; siliceous spicules often altered to chalcedony and (or) replaced by calcite	epibenthonic filter feeders
Ostracods	r; in muddy samples only	disarticulated whole valves	benthonic or nektonic (?) omnivores
Serpulid worm tubes	r	whole and broken tubes	epibenthonic omnivores
Phosphatic material	s	fragmented vertebrate and arthropod hardparts	variety of nektonic and benthonic niches
Plant debris	r; in muddy samples only	finely comminuted plant fragments	land-derived organic detritus

Brachiopod and Bivalve identification from N. Z. Fossil Record Form S18f/500, 506.

TABLE 6/6 Fauna and Flora of the STONY CREEK LIMESTONE

All are widespread unless otherwise indicated. a=abundant, vc=very common, c=common, s=sparse, r=rare

Fossils	Occurrence	Preservation	Ecology
MACROFOSSILS			
Brachiopods	s	disarticulated valves, many broken	epifaunal, low level filter feeders
Bivalves *Athlopecten athleta* *Mesopeplum* *Serripecten*	a at Kohaihai Bluff; elsewhere s	whole and broken disarticulated valves	free swimming bivalves, suspension feeders
Dosinia *Eumarcia* (*Aramarcia*) *Marama*	c at Kohaihai Bluff; s-r elsewhere	usually whole disarticulated valves; many fragments	shallow water suspension feeders or shallow burrowers
Chlamys williamsoni *Modiolus huttoni* *Pallium convexum*	r; Kohaihai Bluff	disarticulated valves, mostly whole	byssiferous bivalves, shallow water suspension feeders
Gastropods *Glycymeris* (*Grandaxinea*)	c at Kohaihai Bluff; r elsewhere	whole disarticulated valves frags.?	free living mollusk; modern species in offshore shell sands and gravels; suspension feeder
Limatula	s	whole	modern species offshore shallow-water grazers

Bryozoa subspherical branching cylinders fenestrate	a; s at Kohaihai Bluff	small fragments; large hemi-subspherical colonies at Stony Ck., Oparara R.	basally attached or encrusting epibenthic carnivores
Solitary corals	r; Stony Creek	whole	basally attached (?), carnivore
Echinoderms	c	plates and spines	mainly semi-infaunal or infaunal deposit feeders
Serpulid worm tubes	r; Stony Ck., Kohaihai Bluff	broken tubes	epibenthic, encrusting omnivores
<u>MICROFOSSILS</u>			
Benthonic foraminifera	vc Limestone Ck; c elsewhere mainly *Amphistegina*	whole, sometimes bored, infrequently micritized	variety of benthonic niches
Planktonic foraminifera	r; Kohaihai Bluff	whole	planktonic
Red algae	s	fragments	encrusting epiflora

Mollusc identification from N. Z. Fossil Record Form S12f/503.

TABLE 6/7 Fauna and Flora of the OPARARA MEMBER

All are widespread unless otherwise stated. a=abundant, vc=very common, c=common, s=sparse, r=rare

MACROFOSSILS	Occurrence	Preservation	Ecology
Brachiopods	s	broken valves	attached epifaunal filter feeders
Molluscs	c; pectens at Happy Valley Saddle	mostly fragments, often bored	epifaunal or semi-infaunal suspension feeders; pectens free swimming suspension feeders
Echinoderms	s	mostly plates, spines	infaunal or semi-infaunal deposit feeders or scavengers
Spatangoid echinoid[1] cf. *Cyclaster*	r, Glasseye Creek	whole, bored and encrusted by serpulid worms and bryozoa	infaunal or semi-infaunal deposit feeders
Serpulid worm tubes	c; Glasseye Creek	broken tubes	epibenthonic encrusters; omnivores
Red Algae	s	fragments, often bored by algae, etc.	epibenthonic encrusting flora
Bryozoa branching encrusting	vc	fragments	epibenthic encrusting carnivores
Solitary corals	r; near Happy Valley Saddle	whole	basally attached colonies, carnivores
Fish teeth	r; Glasseye Creek	whole	nektonic

MICROFOSSILS			
Planktonic foraminifera	s; c at Limestone Creek	whole	planktonic
Benthonic foraminifera	c at Oparara R.; vc near Happy Valley Saddle	whole, bored, often filled with glauconite	variety of benthonic niches

[1]Fossil identification from Henderson (1975), and N. Z. Fossil Record Form S18f/513 (GS 3565).

TABLE 6/8 Bryozoa Content (100) (B/Allochems)

Member	Range	Average	Comments
Oparara Member	5-81	45	mostly fragmentary subcylindrical zoaria
Stony Creek Limestone	10-89	63	fragmentary subcylindrical and subspherical colonies; few bryozoa at Kohaihai Bluff
Kohaihai Limestone	0-32	8	mostly fragments; irregularly shaped encrusting bryozoa at Glasseye Creek and near Happy Valley Saddle
Glasseye Mudstone	0-40	7	only fragments; all types
Kongahu Member	0-80	28	mainly fragments; often extremely abundant

TABLE 6/9 Foraminifera Content (100) (F/Allochems)

Member	Range	Average	Comments
Oparara Member	4-77	28	mostly large benthonics, except at Limestone Creek where planktonics comprise 77 % of allochems; mainly whole
Stony Creek Limestone	1-10	4	large benthonics, like Amphistegina, usually whole
Kohaihai Limestone	2-46	28	mostly large, whole benthonics
Glasseye Mudstone	34-93	61	planktonics, some benthonics; usually whole
Kongahu Member	8-77	36	large benthonics predominate; planktonics common in muddy beds; whole and broken

the Kohaihai Limestone but are the dominant skeletal constituents of the overlying Stony Creek Limestone, except at Kohaihai Bluff, where bryozoa constitute only 10 % of the allochems. They comprise over 80 % of the allochems in the Oparara Member at the Oparara River quarry and near Glasseye Creek. The Oparara Member contains fewer bryozoa near Happy Valley Saddle and at Limestone Creek. Bryozoa are a common and occasionally dominant allochem in the Kongahu Member. Samples of Glasseye Mudstone from burrowed, intercalcated sequences of Kongahu Member and mudstone contain the highest proportions of bryozoa. The sand-free Glasseye Mudstone samples rarely contain bryozoan fragments.

Three morphological types of zoaria are distinguished in the study area. Subcylindrical, nonbranching, or dichotomously branching zoaria are the most common types and are widespread. The length of the zoarium ranges from a fraction of a millimeter to tens of millimeters. Encrusting bryozoa, often forming subspherical colonies several centimeters in diameter, appear predominantly in the Stony Creek Limestone and frequently have hollow centers (Fig. 6/3). These bryozoa probably encrusted some organic substrate, which rotted leaving a hollow axial canal (later filled with mud or sparite). Fenestrate zoaria rarely occur in the Kongahu Member and Stony Creek Limestone.

Foraminifera are abundant in the Nile Group sediments (Table 6/9). Large benthonic forms, such as

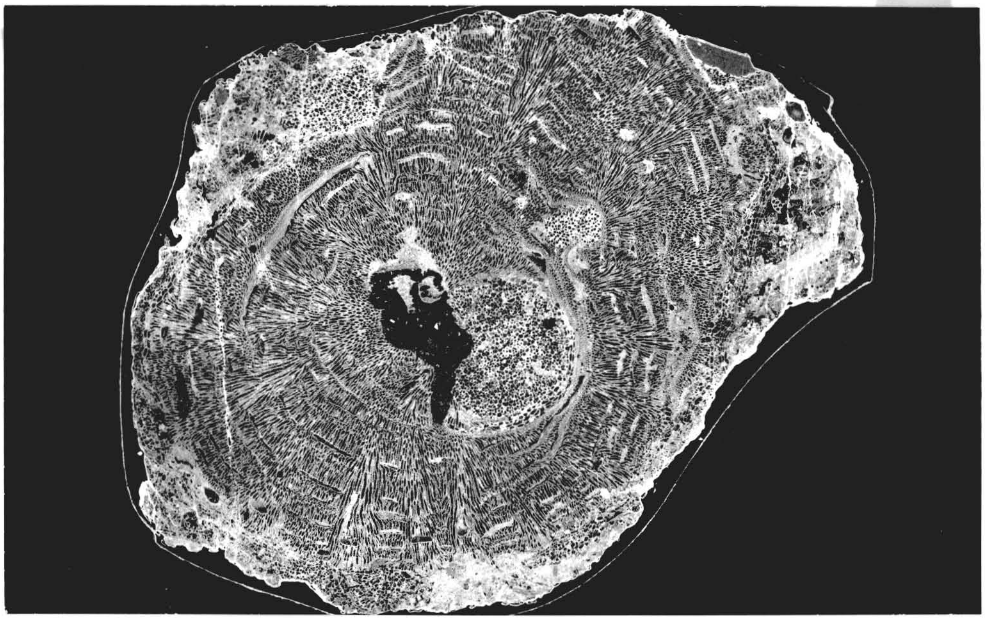


Figure 6/3 Sub-spherical bryozoan colony from the Stony Creek Limestone: lime quarry near the mouth of the Oparara River (sample UC 7453 A). Note encrusting habit and sparite-filled central cavity. Greatest diameter of zoarium equals 53 mm. Positive print from acetate peel.

Amphistegina, are the dominant foraminifera in the Kohaihai and Stony Creek Limestones. Planktonic foraminifera constitute the bulk of the allochems of the Oparara Member at Limestone Creek; elsewhere, this member contains fewer foraminifera, most of which are benthonic. Planktonic foraminifera are the dominant allochems in the Glasseye Mudstone. The mudstone normally contains a few small benthonic foraminifera; large benthonic foraminifera are most plentiful where bioturbation or slumping has mixed mudstone and Kongahu Member lithologies. Abundant, large hyaline benthonic foraminifera occur in the Kongahu Member.

Echinoderm fragments, consisting mainly of broken plates and spines, are common constituents of the Nile Group sediments and are the dominant allochems in the Kohaihai Limestone (Table 6/10). Whole echinoderms are rare and have been found only in the Oparara Member and Glasseye Mudstone. Spines are the most frequently encountered echinoderm fragments in the Glasseye Mudstone. Sparse, crinoid, columnal segments occur in the Kohaihai Limestone near Stony Creek.

Mollusc and brachiopod fragments are found mainly in the Kohaihai and Stony Creek Limestones and the Oparara Member (Table 6/11). The Kohaihai Limestone contains mostly brachiopod and bivalve fragments. Whole and fragmented brachiopods comprise 85 % of the

TABLE 6/10 Echinoderm Content (100) (E/Allochem)

Member	Range	Average	Comments
Oparara Member	1-13	7	mostly fragments, a few whole spatangoid echinoids, cf. Cyclaster
Stony Creek Limestone	2-20	10	mainly fragments
Kohaihai Limestone	tr-67	42	mainly fragments, some crinoid fragments
Glasseye Mudstone	0-33	7	fragments especially spines some whole spatangoid echinoids
Kongahu Member	0-10	4	fragmentary

tr=trace

TABLE 6/11 Brachiopod and Mollusc Fragment Content (100) (S/Total Allochems)

Member	Range	Average	Comments
Oparara Member	tr-20	7	mainly broken bivalves; whole pectens at Happy Valley Saddle and Glasseye Creek
Stony Creek Limestone	tr-85	19	whole bivalves, brachiopods, gastropods at Kohaihai Bluff; mainly fragments elsewhere
Kohaihai Limestone	tr-10	5	mainly fragments; some whole brachiopods and pectens at Kohaihai Bluff
Glasseye Mudstone	0- 4	1	mainly fragments; some whole bivalves and brachiopods including Liothyrella magna
Kongahu Member	0-20	2	mostly bivalve and brachiopod fragments

tr=trace

allochems in the Stony Creek Limestone at Kohaihai Bluff. Many whole bivalves, especially pectens, and lesser numbers of brachiopods and gastropods are concentrated in beds that are nearly monospecific. Elsewhere, the Stony Creek Limestone contains mainly broken valves. The Kongahu Member contains mostly fragmented shells, most of which are bivalves. Ostrea fragments are commonly replaced by dolomite and are found in the Kongahu Member at View Hill Saddle and Gentle Aniie Point. Rare, whole brachiopods and bivalves occur in pebbly mudstones and in the Glasseye Mudstone near Little Wanganui Head. Whole pecten valves occur in the limestone of the Oparara Member at Glasseye Creek and near Happy Valley Saddle.

Red algae are major constituents only in the Kongahu Member (Table 6/12). The algae are generally of an encrusting type, resembling Lithothamnium, and frequently form rhodolites (Fig. 4/19). The red algae coat a variety of nuclei, including bryozoa, shell fragments, and detrital fragments that range in size from sand grains to small cobbles. The algal coatings, which develop evenly around the nuclei, are generally less than 5 mm thick. Fragments of delicately branching coralline algae (cf., Amphiroa) occur sparingly in the Kongahu Member and Stony Creek Limestone.

Sponge spicules contribute up to 55% of the allochems in some samples of Glasseye Mudstone (Table 6/13). Spicules

TABLE 6/12 Red Algae (100) (RA/Total Allochems)

Member	Range	Average	Comments
Oparara Member	tr-12	3	fragments
Stony Creek Limestone	0-10	2	fragments, some articulated coralline algae (?)
Kohaihai Limestone	0- 2	tr	small fragments
Glasseye Mudstone	0- 6	1	generally small fragments, mostly in sandy mudstone near Kongahu Member beds
Kongahu Member	0-69	14	common constituent; small fragments and whole rhodolites

tr=trace

TABLE 6/13 Sponge Spicule Content (100) (Sp/Total Allochems)

Member	Range	Average	Comments
Oparara Member	0- 2	tr	megascleres at Limestone Creek only
Stony Creek Limestone	0-tr	0	as above
Kohaihai Limestone	0	0	————
Glasseye Mudstone	0-55	19	mostly whole monaxial, triradial, and quadriradial megascleres; probably from siliceous sponges although many spicules now composed of calcite and chalcedony
Kongahu Member	0-53	6	as above; commonly occur in muddy samples. Fragments of siliceous sponge colonies very rare.

also occur in the Kongahu Member, particularly in beds with a muddy matrix. The spicules are mainly of the megasclere type and measure up to 200 μ in diameter and 2.3 mm in length (Fig. 6/4). A hollow central canal is present in most of the spicules. Spicule types include triaxons, triaenes, protriaenes, and irregular meshworks of dichotriaenes (terminology from Moore, 1955). Triradiate and quadriradiate megascleres with central canals are usually associated with siliceous sponges (Scholle, 1971). Identical spicules, which are composed of calcite, chalcedony, and opal (isotropic silica), usually occur together in each sample. Central canals are best preserved in the opal and chalcedony spicules; this suggests that the spicules were originally siliceous and were later replaced by calcite. Interlocking masses of siliceous microscleres (4 μ diameter, maximum length of 180μ) occur in sample UC 7455 J from Gentle Annie Point (Fig. 6/5) and may represent portions of siliceous sponge colonies.

Ostracod valves occur sparingly in the Glasseye Mudstone and in a few very muddy beds of the Kongahu Member (Samples UC 7465 P and 7465 T). Ostracods comprise 23 % of the allochems in sample UC 7467 K. This sample was taken from a white pelletoidal micrite that covered a small granite boulder in a major channel fill near Little Wanganui Head. The allochem association of the micrite (planktonic foraminifera and ostracods) contrasts with the red algae, benthonic foraminifera and bryozoa assemblage of the surrounding Kongahu

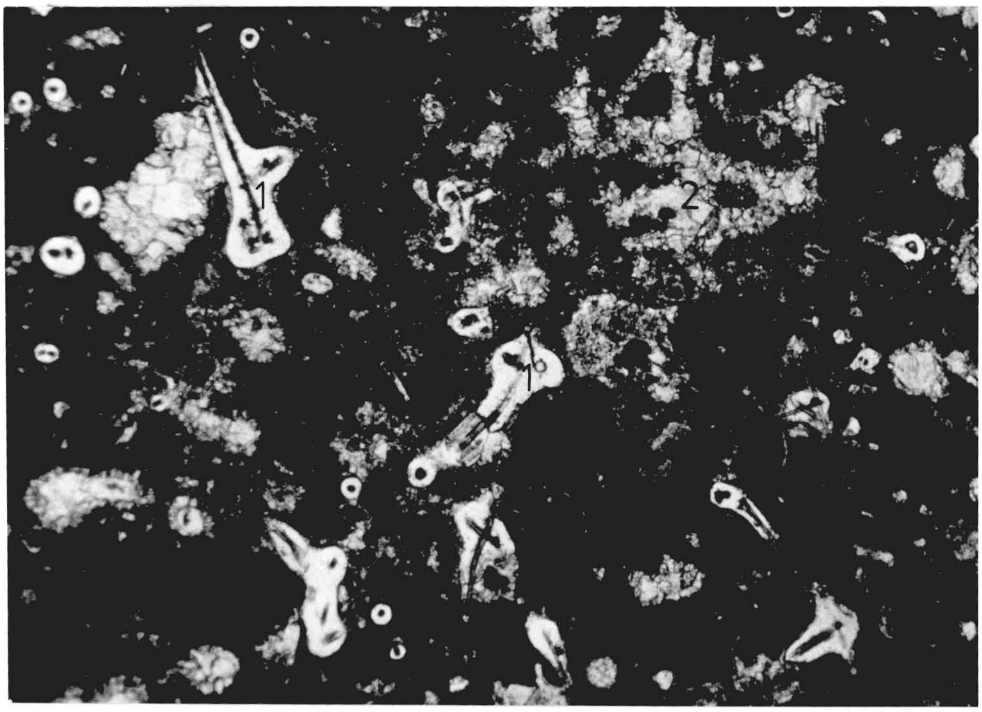
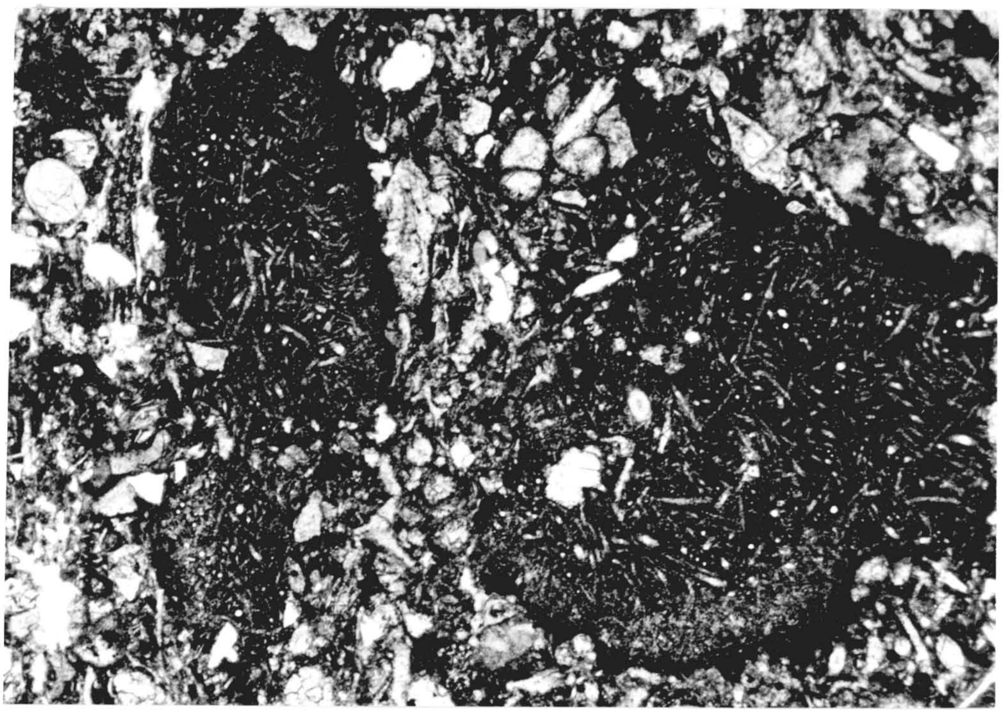


Figure 6/4 Fragment of siliceous sponge colony in Glasseye Mudstone. The amorphous silica spicules are partly replaced by (1) chalcedony and (2) calcite. Note the central canals in the spicules. Field of view equals 2.07 mm. Sample 7465 Q. Plane polarized light.

Figure 6/5 Two fragments of probable siliceous sponge colonies composed of interwoven masses of opaline microsclerites (sample UC 7455 J). Field of view equals 2.07 mm. Plane polarized light.



Member sediment (e.g., Sample UC 7467 I). The micrite, which coats the boulder, could have been emplaced if the boulder rolled through pelletoidal mud prior to final deposition. Alternatively, the coating may represent fine sediment that was trapped and bound by non-calcareous algae growing on the boulder.

Fragments of serpulid worm tubes were found in several coastal Kongahu Member beds and in the Stony Creek Limestone at Kohaihai Bluff and Stony Creek. Serpulid worms also occur in the Oparara Member, particularly at Glasseye Creek, where serpulid fragments account for 3 %-6 % of the allochems (samples UC 7465 A and 7465 B). The chalky-white tubes, which grow up to 20 mm long, are easy to recognize in thin section, because they possess cone-in-cone outer skeletal layers.

Radiolaria appear in several Glasseye Mudstone and muddy Kongahu Member samples. The tests are usually whole, and in sample UC 7465 they comprise 3 % of the allochem total.

Sparse, whole solitary corals were noted in the middle Kohaihai Limestone at Kohaihai Bluff, the lower Stony Creek Limestone at Stony Creek, and the Oparara Member near Happy Valley Saddle.

Traces of chitino-phosphatic material were found in all members of the Nile Group but were most common in the Glasseye Mudstone. Broken arthropod carapaces probably account for most of the fragments. Shark's teeth were found in the Kohaihai Limestone and Oparara Member. Fish skeletons were noted at Falls Creek (App. III) and Kongahu Point. The well preserved skeletons were only slightly disturbed by burrowing. This suggests that the sedimentation rate was high in the vicinity of the coastal sections during the Oligocene. Cetacean bones, including a whole skull, were recovered from loose blocks of Glasseye Mudstone south of Little Wanganui Head, App. III). Lower (?)Oligocene cetacean remains are quite rare and the Little Wanganui specimens may represent the oldest Mysticetes yet found (E. Fordyce, pers. comm.).

Non-skeletal allochems

Discrete grains of glauconite are present in all members of the Nile Group but are only abundant in the Kohaihai Limestone (Table 6/14). The dark green, ovoid grains are often stained dark brown by the oxidation of included pyrite. The pale green color of the basal Stony Creek Limestone at Kohaihai Bluff is a result of minute glauconite inclusions in the matrix and glauconite infillings of allochems.

Well preserved leaves and chips of wood several centimeters long are commonly encountered in the Glasseye Mudstone, particularly in the upper reaches of Falls and Glasseye Creeks, where the mudstone exudes a petroliferous odor when struck by a hammer. Finely

TABLE 6/14 Glauconite Content (100) (G/Total Allochems)

Member	Range	Average	Comments
Oparara Member	tr	tr	very sparse, small irregular grains; abundant infillings of allochems
Stony Creek Limestone	0- 1	tr	as above, some infilling of allochems
Kohaihai Limestone	tr-88	27	mostly shapeless grains; some pellet-shaped 0.6 mm long often replaced by pyrite and iron stained. Abundant infilling of allochems
Glasseye Mudstone	0- 1	tr	small (40μ) dark green to brown grains, often replaced by pyrite; minor infilling of allochems
Kongahu Member	0- 3	tr	shapeless dark green grains most common in upper part of member; moderate infilling of allochems

tr=trace

TABLE 6/15 Plant Detritus Content (100) (P/Total Allochems)

Member	Range	Average	Comments
Oparara Member	0-tr	0	trace at Limestone Creek
Stony Creek Limestone	0	0	————
Kohaihai Limestone	0-tr	0	————
Glasseye Mudstone	0-20	4	leaves and twigs common; abundant in finely laminated carbonaceous layers which often occur above Kongahu Member beds; Falls Creek Glasseye Mudstone has petroliferous odor
Kongahu Member	0-15	1	in muddy beds

.tr=trace

comminuted plant debris is a minor constituent of the Glasseye Mudstone and muddy Kongahu Member beds (Table 6/15).

Irregular ovoid <u>pelletoids</u>, measuring 60 long, were found in a loose boulder of Glasseye Mudstone (Sample UC 7457 C) at Kongahu Point (Fig. 6/6). The pelletoids have gradational boundaries with the recrystallized micrite matrix (microsparite). Sample UC 7463 C (a concretionary band in the Glasseye Mudstone) has a clotted texture reminiscent of a poorly preserved pelletoidal mudstone. There, samples suggest that the Glasseye Mudstone contained large numbers of pellets, which were not generally preserved.

<u>Intraclasts</u> occur in many beds of the Kongahu Member. The intraclasts range in size from a few millimeters to over 1 m; the average length is 20-40 mm (Figs. 6/7 and 6/8). The clasts consist of grey, calcareous mudstone, which has a composition identical to that of the Glasseye Mudstone. The clasts generally have a flattened lenticular shape with the longest dimension parallel to the bedding planes. Many of the clasts exhibit bending or attenuation, which is the result of soft sediment deformation (Fig. 6/8). The clasts commonly cluster in the upper portion of fine grained beds of the Kongahu Member (Fig. 4/12).

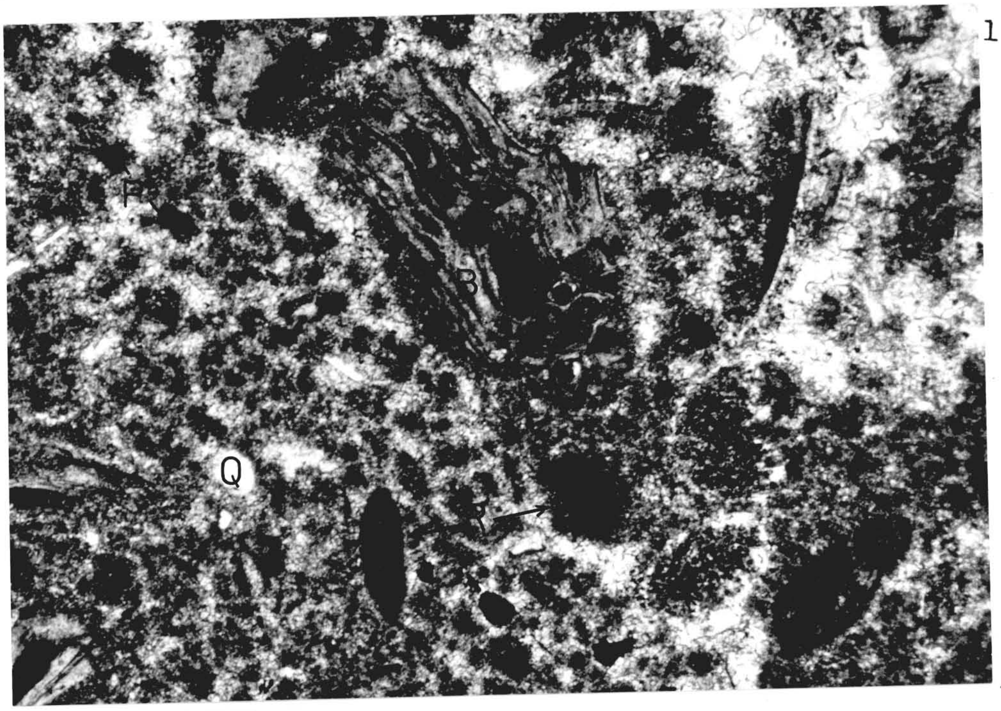


Figure 6/6 Pelletoids (P) in matrix of micrite, microsparite, and sparite. Q=quartz; R=red algal fragment; B-bryozoan fragment. Sample UC 7457 C. Field of view is 2.07 mm. Plane polarized light.

Figure 6/7 Large mud clast bisected by clastic dike in Kongahu Member bed at Little Wanganui Head. Clast composition is identical to that of the Glasseye Mudstone. The sharp planar edges of the mudstone clast suggest that the mudstone had a stiff plastic consistency when it was transported. Diameter of coin equals 32 mm.

Figure 6/8 Swarm of small mud clasts in upper portion of massive Kongahu Member bed. Note the lenticular, somewhat attenuated shape of the clasts. Arrow points to rhodolith. Photo taken on coast about 1 km south of Little Wanganui Head. Diameter of lense cap is 55 mm.

CHAPTER 7

DIAGENESIS

The chapter includes brief descriptions of the diagenetic features within the Nile Group sediments. Tables 7/1-7/6 list the diagenetic features that were noted in thin section.

Several types of carbonate cement are distinguished in the Nile Group sediments. Sparry calcite (orthosparite) and syntaxial overgrowths on echinoderm fragments tightly cement the Stony Creek and Kohaihai Limestones and the Kongahu and Oparara Members. Microsparite cements several muddy Kongahu Member and Oparara Member samples and micrite and detrital clays bind the Glasseye Mudstone. Micrite cements the Stony Creek Limestone at Kohaihai Bluff.

Orthosparite cement occurs as fine to large, anhedral to subhedral crystals (Fig. 7/1). The crystals that fill the center of the more spacious voids are larger than those along the void margins. Commonly, void spaces are so small that no increase in crystal size is apparent. Only one generation of orthosparite crystals was noted. Opposing sets of sparite crystals show compromise boundaries even though pressure solution effects are evident between allochem grains; therefore, sparry cementation is a relatively late diagenetic event.

TABLE 7/1 Diagenetic Features of the KOHAIHAI LIMESTONE

Subjective Scale: a=abundant; c=common; s=sparse; r=rare

Sample	1a	1b	1c	2a	2b	3	4	5	6	7	8	9	10	11	12
7451 E	s	s	s	-	-	-	c	-	c	s	s	c	s	-	-
7451 D	-	s	s	-	-	-	c	s	c	c	s	c	c	-	s
7451 C	-	s	c	-	-	-	c	s	c	c	c	c	c	-	-
7451 B	-	s	c	-	-	c	-	s	s	s	c	c	s	-	s
7452 C	s	s	c	-	-	c	c	s	s	c	c	c	c	-	c
7452 B	s	s	s	-	-	-	c	-	-	s	s	s	-	-	s
7452 A	-	-	s	-	-	-	s	c	-	c	c	c	c	-	s

Key[1]

1a	Calcitization	Feldspar Alteration	6	Micritization of allochems
1b	Sericitization		7	Endolithic boring
1c	Vacuolization		8	Pyrite
2a	Allochems replaced by chert	Chert	9	Iron oxides
2b	Matrix replaced by chert		10	Glauconite in allochems
3	Aggrading recrystallization of mud		11	Dolomite
4	Syntaxial overgrowths		12	Pressure solution effects
5	Recrystallization of allochems			

[1]This key is used for Tables 7/1-7/5.

TABLE 7/2 Diagenetic Features of the STONY CREEK LIMESTONE

Subjective Scale: a=abundant; c=common; s=sparse; r=rare

Sample	1a	1b	1c	2a	2b	3	4	5	6	7	8	9	10	11	12
7452 G	-	-	-	-	-	s	c	s	-	s	-	-	s	-	s
7452 F	-	-	-	-	-	s	c	s	-	s	-	-	-	-	s
7452 E	s	s	c	-	-	c	c	s	-	s	s	s	s	-	c
7452 D	c	c	c	-	-	c	c	c	-	s	c	s	s	r	c
7451 G	-	-	s	-	-	-	s	c	-	c	-	s	s	-	s
7451 F	-	-	s	-	-	-	-	c	-	c	c	c	c	-	s
7451 E	s	-	s	-	-	-	-	s	s	c	s	c	s	-	-
7453 A	-	-	-	-	-	s	c	c	-	s	s	s	s	-	c
7454 A	-	s	c	-	-	-	c	-	-	s	c	c	s	-	c
7454 B	s	-	s	-	-	-	c	s	-	s	-	-	s	-	c

TABLE 7/3 Diagenetic Features of the OPARARA MEMBER

Subjective scale: a=abundant; c=common; s=scarce; r=rare

Sample	1a	1b	1c	2a	2b	3	4	5	6	7	8	9	10	11	12
7453 B	s	s	c	-	-	-	c	-	-	a	-	c	c	-	c
7454 C	s	-	s	c	c	-	s	s	-	s	c	c	s	-	s
7465 A	-	-	-	-	-	a	c	s	r	a	s	r	s	-	s
7465 B	s	-	s	-	-	a	c	s	r	a	s	-	c	-	s
7464 B	s	c	s	-	-	c	c	c	-	c	a	c	c	c	c
7464 A	c	c	c	-	-	s	c	a	r	a	c	s	a	c	c

TABLE 7/4 Diagenetic Features of the GLASSEYE MUDSTONE

Subjective Scale: a=abundant; c=common; s=scarce; r=rare

Sample	1a	1b	1c	2a	2b	3	4	5	6	7	8	9	10	11	12
7461 D	r	s	c	s	-	-	-	c	r	s	c	s	-	-	-
7461 F	s	-	s	s	-	-	-	r	r	r	s	s	r	-	s
7561 J	-	-	r	s	-	s	r	c	s	s	c	c	-	-	-
7461'O'	-	-	s	s	-	-	-	s	c	s	c	s	-	s	-
7461 K	r	-	r	s	-	-	-	c	r	s	c	s	-	-	-
7462 B	r	s	s	c	-	-	-	c	c	s	c	s	r	-	-
7463 A	r	-	r	r	-	-	-	c	r	s	c	s	-	-	-
7463 C	-	-	-	r	-	-	-	c	a	s	c	s	-	-	-
7464 C	r	r	r	c	-	-	-	c	s	r	c	s	-	a	-
7455 C	-	-	-	s	-	-	-	-	-	r	c	s	-	-	-
7455 P	s	s	c	s	-	-	-	-	-	r	s	-	-	-	-
7455 M	s	c	c	c	s	-	-	s	-	r	-	-	-	a	r
7458 N	s	-	c	c	-	-	-	s	-	s	c	c	s	-	-
7467 P	-	-	r	c	-	-	-	c	a	s	c	c	r	-	s
7467 M	s	s	c	r	-	-	-	s	s	s	c	s	r	-	-
7457 F	s	r	c	c	-	-	-	c	c	c	c	r	r	-	c
7466 X	-	r	s	s	-	-	r	c	-	c	c	r	r	-	r
7466 W	-	-	-	a	a	-	-	s	c	s	c	c	-	-	-
7466 E	r	-	s	s	-	-	r	c	-	c	c	r	r	-	r
7465 W	-	-	-	c	-	-	r	c	c	s	s	-	-	r	s
7465 V	r	-	s	c	-	-	r	s	s	s	s	r	-	-	s
7465 N	-	r	r	c	-	-	-	-	-	r	c	r	-	-	-
7465 C	-	-	-	r	-	-	s	c	c	s	s	-	-	-	-
7467 T	-	-	s	r	-	-	-	s	-	-	c	s	r	s	r

TABLE 7/5 Diagenetic Features of the KONGAHU MEMBER

Subjective Scale: a=abundant; c=common; s=sparse; r=rare

Sample	1a	1b	1c	2a	2b	3	4	5	6	7	8	9	10	11	12
7457 B	-	s	c	-	-	-	-	-	-	-	-	-	-	-	-
7457 A	c	s	c	s	-	-	c	-	-	s	s	-	-	-	c
7458 K	c	s	c	s	-	c	-	-	-	s	s	-	-	-	c
7455 A	c	s	c	-	-	-	c	c	r	r	r	-	-	-	c
7455 B	-	-	c	c	-	c	c	c	s	s	c	-	-	c	c
7455 E	c	-	c	-	-	c	c	-	s	s	s	-	-	s	c
7455 G	s	s	c	s	-	c	s	s	s	s	-	-	s	-	s
7455 H	s	s	c	c	-	c	c	-	s	s	-	-	-	c	s
7455 I	s	s	c	s	-	c	-	-	s	s	s	-	-	r	s
7455 L	s	-	c	c	-	c	s	c	s	s	r	-	s	s	c
7455 K	s	s	c	c	-	c	s	a	s	c	c	-	-	-	c
7455 J	s	-	c	s	-	-	-	s	s	s	s	r	-	c	s
7467 P	c	s	s	-	-	s	s	c	-	c	c	c	-	-	a
7467 I	s	c	c	-	-	c	s	-	-	s	s	-	-	-	s
7467 B	s	s	c	-	-	c	s	r	r	s	s	r	-	-	s
7466 W	c	-	c	c	a	-	-	-	s	s	c	s	-	-	s
7466 V	s	c	c	r	-	c	c	c	s	s	c	-	-	-	s
7466 U	r	r	c	s	-	a	c	c	c	c	r	-	-	-	s
7466 T	s	s	c	s	-	a	r	s	-	s	r	r	s	-	s
7466 S	s	c	c	-	-	r	a	c	-	s	r	-	-	-	s

7466 P	r	r	s	s	-	a	s	c	s	s	-	-	r	-	s
7466 N	s	r	c	c	-	c	c	-	-	s	r	r	-	s	c
7466 M	s	c	c	c	-	s	c	r	-	s	r	-	-	-	s
7465 X	s	s	c	c	r	r	s	a	s	c	c	c	-	r	s
7465 W	s	-	s	r	-	s	c	c	r	s	c	-	-	r	c
7465 V	r	-	s	s	-	s	c	c	c	c	s	r	-	-	c
7465 T	s	-	s	s	-	s	-	-	s	s	c	r	-	a	s
7465 P	s	c	c	c	-	-	r	s	-	s	s	r	-	-	r
7465 N	s	c	c	c	-	s	r	-	-	s	c	r	r	s	s
7465 M	s	s	c	c	r	s	-	r	-	s	s	r	r	a	s
7465 K	s	s	s	c	r	s	c	s	s	r	r	r	r	r	s
7465 H	r	-	r	c	-	-	-	r	c	s	r	-	-	-	s
7465 C	r	s	s	c	-	c	c	s	c	s	s	-	-	-	c
7461 C	r	c	c	c	-	-	-	s	s	s	c	s	r	-	r
7461 F	c	s	c	c	-	-	-	s	s	r	s	-	-	-	s
7461 G	c	s	c	c	r	c	s	c	s	r	c	s	c	-	c
7461 H	s	s	s	r	-	-	-	s	s	c	c	s	-	-	r
7461 'O'	r	-	s	c	-	s	c	c	s	s	s	-	-	-	c
7462 C	-	-	s	s	r	s	c	s	c	s	c	s	s	-	s
7463 B	r	-	s	c	-	s	-	c	r	c	c	s	-	-	-

TABLE 7/6 SUMMARY OF DIAGENESIS IN THE NILE GROUP

Diagenetic Feature	Comments
Feldspar alterations	Widespread, but most common in feldspathic Kongahu Member beds
Silicification of Allochems and Matrix	Mainly Kongahu Member and Glasseye Mudstone
Orthosparite Cement and Void Fillings	Mainly in mud-free sediments; void fillings in all members
Aggrading recrystallization of calcareous mud matrix	Common in all members except the Glasseye Mudstone; aggrading recrystallization of micrite within foram tests, bryozoan zooecia, etc., widespread
Recrystallization of allochems	Widespread
Micritization of allochems	Common in Kohaihai Limestone, scarce elsewhere
Syntaxial overgrowths	A common cement type in all members except the Glasseye Mudstone
Dolomite	Occurs sporadically in the Kongahu Member and Glasseye Mudstone
Pyrite in allochems, matrix	Widespread
Glauconite in allochems	Rare in Kongahu Member, Glasseye Mudstone; common elsewhere
Pyrite and glauconite alteration to form Fe oxides	Widespread, but less common in Kongahu Member
Pressure solution effects	Rare in Glasseye Mudstone; common elsewhere
Microboring	Widespread, but most intense in the Oparara and Kongahu Members

Figure 7/1 Bryozoan fragments (B) cemented by sparite (S). Microsparite (M) fills some of the bryozoan zooaria. Sample UC 7452 F . Plane polarized light. Field of view equals 2.07 mm.

Syntaxial overgrowth on echinoderm fragments is a common cement type in all Nile Group sediments, except the Glasseye Mudstone (Fig. 7/2). The Nile Group sediments have an inverse relationship between mud content and the abundance of syntaxial overgrowths. (Fig. 7/3). Mud coatings around echinoderm fragments apparently hindered the formation of overgrowths. The muddy matrix possibly insulated the surface of the echinoderm grain or reduced circulation of pore fluids, thereby inhibiting overgrowth formation. Syntaxial replacement rims, which form at the expense of carbonate mud, were not seen.

Aggrading recrystallization of carbonate mud is generally absent in the Glasseye Mudstone, although it occurs regularly in the other members. The recrystallization results in the formation of microsparite with a crystal size between 5 and 20μ. The microsparite may be the dominant cement type or may appear as patches within the muddy matrix. Allochems within the microsparite are usually well preserved. Microsparite formation within foraminifera tests and bryozoa zooecia is a widespread phenomenon. This internal microsparite often occurs when no recrystallization of the matrix mud is evident. Apparently, the rotting interiors of the zooecia provided a favorable environment for the recrystallization of carbonate mud.

The decomposition of organic material in the early stages of diagenesis probably initiated cementation. Compaction of the sediment provided the necessary flow of carbonate-bearing solutions for later cementation.

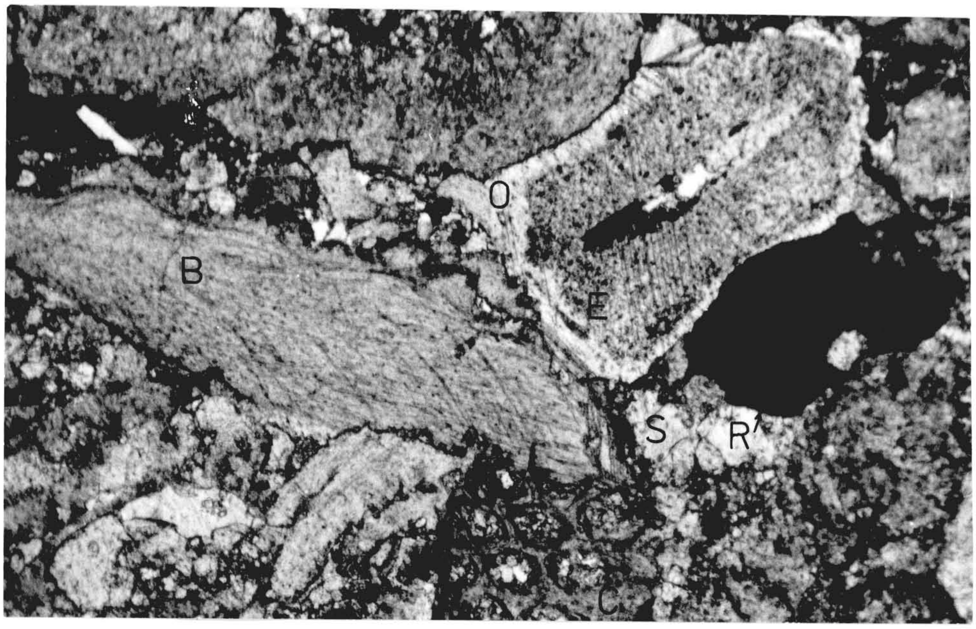


Figure 7/2 Echinoderm (E), brachiopod (B), bryozoan (C) fragments and pyritized fragment of red algae (R) cemented by sparite (S) and syntaxial overgrowths (O). Note numerous stylolitic intergranular contacts. Sample UC 7454 A ; plane polarized light; field of view is 2.07 mm.

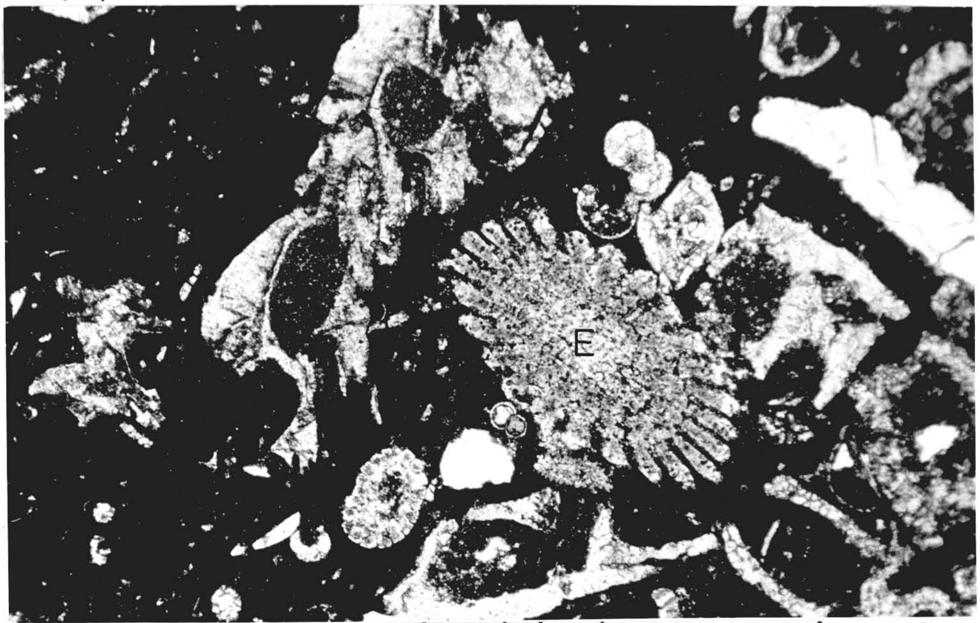


Figure 7/3 Echinoderm spine (E) with benthonic and pelagic foraminifera and bryozoan fragments in muddy matrix (Sample UC 7465 P). Echinoderm fragments in Glasseye Mudstone do not have syntaxial overgrowths. Plane polarized light. Field of view is 2.07 mm.

Pressure solution released substantial amounts of carbonate for cementation.

The carbonate concretion (Fig.4/38) is apparently composed of calcite; numerous very small pyrite framboids are concentrated in burrows. The undeformed burrows suggest that the concretion was formed during the early stages of diagenesis prior to compaction. The presence of pyrite within the burrows implies that the burrows were mucus-lined or filled with mucus-covered, organic-rich fecal pellets. Lippmann (1955, cited by Muller, 1967) proposed the following formational sequence for similar concretions. The decomposition of organic material produced ammonia, which locally raised the pH. With increasing pH, calcite precipitated from saturated pore solutions. This precipitation locally reduced the carbonate concentration in the surrounding waters and caused more carbonate solutions to diffuse towards the "fossil". This calcite solution pump continued to operate until production of ammonia ceased.

Degrading recrystallization of allochems, or micritization, is a widespread but uncommon phenomenon. Thin micrite rinds form around some allochems, particularly shell fragments. Red algal fragments are occasionally micritized and show no structural detail. The causes of micritization are poorly understood, although endolithic boring sponges, algae, and fungi probably play a significant role. Micritization is probably an early diagenetic event.

Although not strictly a form of diagenesis, endolithic boring by algae, sponges, and fungi is important in early diagenetic processes. Algal borings (Fig. 7/4) are widespread, but are most common in the Oparara Member and are least common in the Glasseye Mudstone. Endolithic borings are responsible for major size reductions of allochem grains and for the production of fine grained carbonate. Boring algae occupy a wide depth range but are most active within the photic zone, particularly in depths between 25 and 50 m (Halsey and Perkins, 1970).

Recrystallization of allochems occurs in all Nile Group sediments. Mosaics of sparry calcite replace the allochems, often preserving portions of the internal allochem structure (Fig. 7/4). Mollusc and bryozoan fragments and large benthonic foraminifera are the most commonly recrystallized allochems.

Authigenic pyrite occurs in all Nile Group sediments. Three morphological pyrite types were noted: (1) spherical aggregates of crystals (up to 80 μ in diameter), which are the commonest form; (2) cubes up to 80 μ in diameter, which are most plentiful in the Glasseye Mudstone; and (3) fine "sooty" pyrite, which

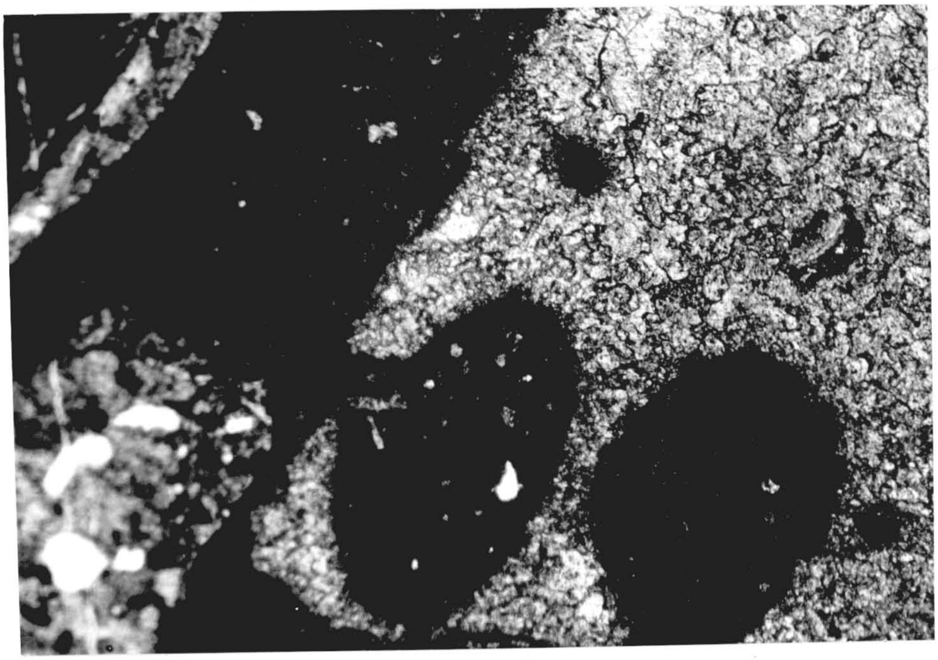


Figure 7/4 Shell fragment recrystallized without preservation of internal structure. Large mud-filled borings are visible. Stony Creek Limestone, Kohaihai Bluff, sample UC 7451 F; plane polarized light; field of view is 2.60 mm.

impregnates and covers the surfaces of allochems, particularly bryozoan fragments in the Kongahu Member, Glasseye Mudstone, and Oparara Member (Fig. 7/ 5). The decomposition of organic material by anaerobic bacteria probably produced the locally reducing low pH environments, which are favorable to pyrite formation.

The spherical pyrite aggregates are commonly distributed throughout the muddy matrix and along the interior surfaces of allochems (e.g., Fig. 7/6). The presence of numerous tiny pyrite cubes results in the light grey color of the Stony Creek Limestone at Limestone Creek. Glauconite and organic material frequently contain cubes and aggregates of pyrite.

The "sooty" films of pyrite that coat bryozoan and other allochem fragments occur predominantly in the Kongahu Member; they formed prior to cementation. Milliman, Pilkey, and Blackwelder (1968) detected similar pyrite-coated and impregnated fossils in the shelf sediments off the North Carolina coast. The pyritiferous allochems proved to be relict Pleistocene fossils that were mixed with Recent carbonates. It is hypothesized that the pyrite-coated allochems of the Nile Group may represent a similar relict fossil assemblage. The older(?) fossils were possibly mixed with more recent allochems by slumping and burrowing.

Pyrite was the only authigenic sulfide mineral found in the Nile Group. Alteration of much of the pyrite to hematite and limonite occurred during later diagenesis and outcrop weathering.

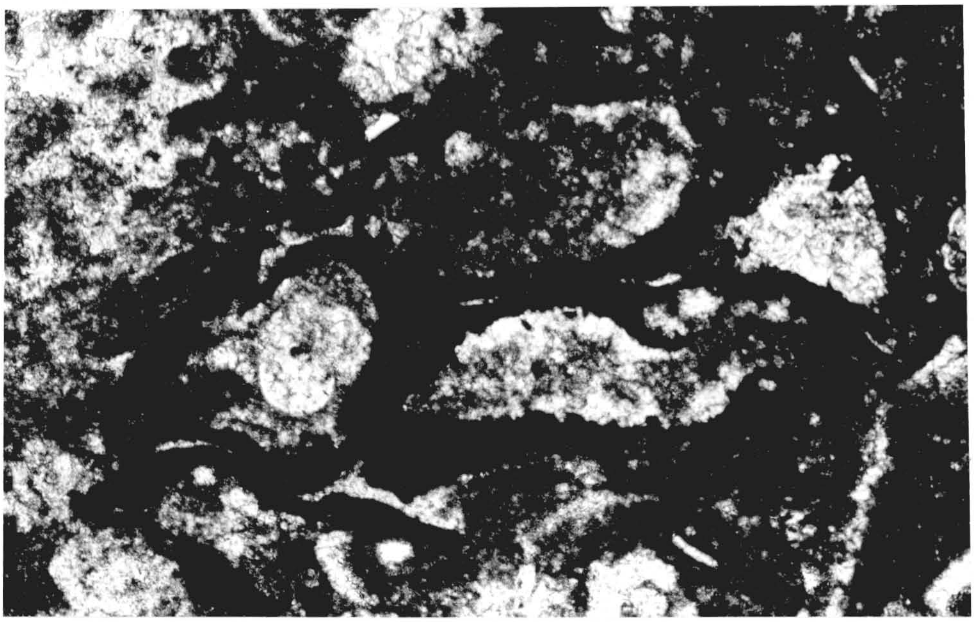


Figure 7/5 "Sooty" pyrite impregnating bryozoan fragment in matrix of micrite and microsparite. Sample UC 7465 P Plane polarized light. Field of view is .54 mm.

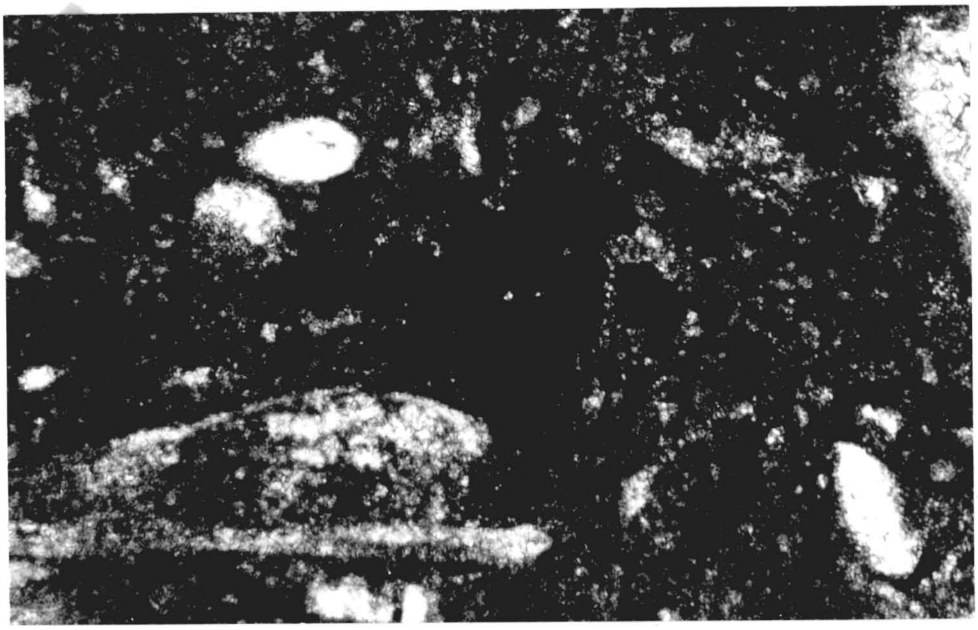
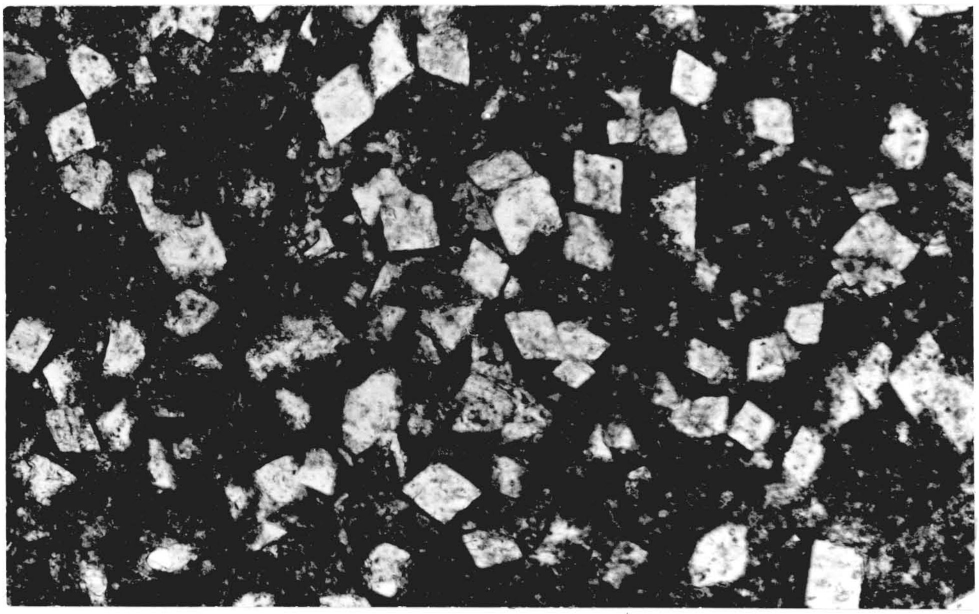


Figure 7/6 Spherical aggregates of pyrite (dark masses in center) in calcareous detrital mud. (sample UC 7465 P) Plane polarized light. Field of view is .54 mm.

Muddy samples of the Kongahu Member, Glasseye Mudstone, and Stony Creek Limestone contain sparse, euhedral rhombohedrons of dolomite, 10-60μ long. The rhombohedrons usually exhibit cloudy cores that are surrounded by clear rims (Fig. 7/7). The clarity of the rims may be attributed to a later phase of dolomitization. The rhombohedrons generally replace the fine grained carbonate and detrital mud matrix; allochem replacement is rare. Dolomite was detected only once in the calcarenites of the Karamea area; it was not seen in the mud-free sediments of the Kongahu Member. This distribution of dolomite agrees with the observation of Perkins (1963) and many other petrographers that micritic rocks are more susceptible to dolomitization. The muddy rocks may be more readily dolomitized because of their high porosity and the large surface area of the micrite grains (Perkins, 1963). Chillingar, Bissell, and Wolf (1967) suggested that dolomitization occurs in strongly to weakly reducing environments that have a high alkalinity and a pH greater than 8. The formational mechanism of the dolomite is unknown. The inversion of high magnesium calcite to low magnesium calcite (possibly by the absorbtion of calcium by montmorillonite) may have been sufficient to raise the Mg/Ca ratio of the pore water (Blatt, Middleton, and Murray, 1972). Dolomitization probably occurred during the early to late burial stages of diagenesis, and it may have locally preceeded large scale silicification of the sediment (Fig. 7/8) (Plate I).

Figure 7/7 Dolomite rhombohedrons in calcareous detrital mud. Note cloudy cores and clear rims of the crystals. Sample UC 7455 M; Gentle Annie Point; plane polarized light; field of view is .865 mm.



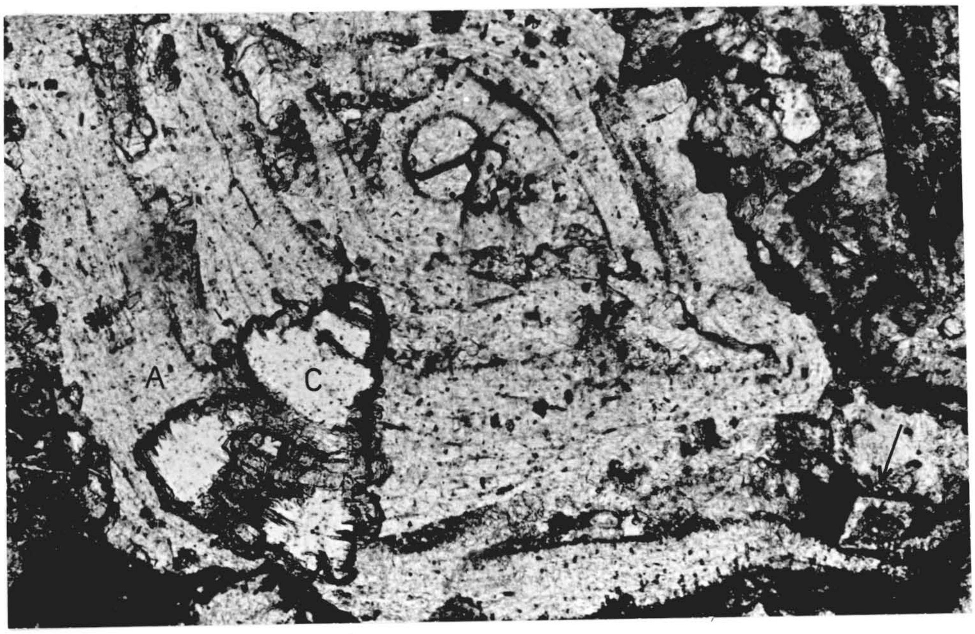
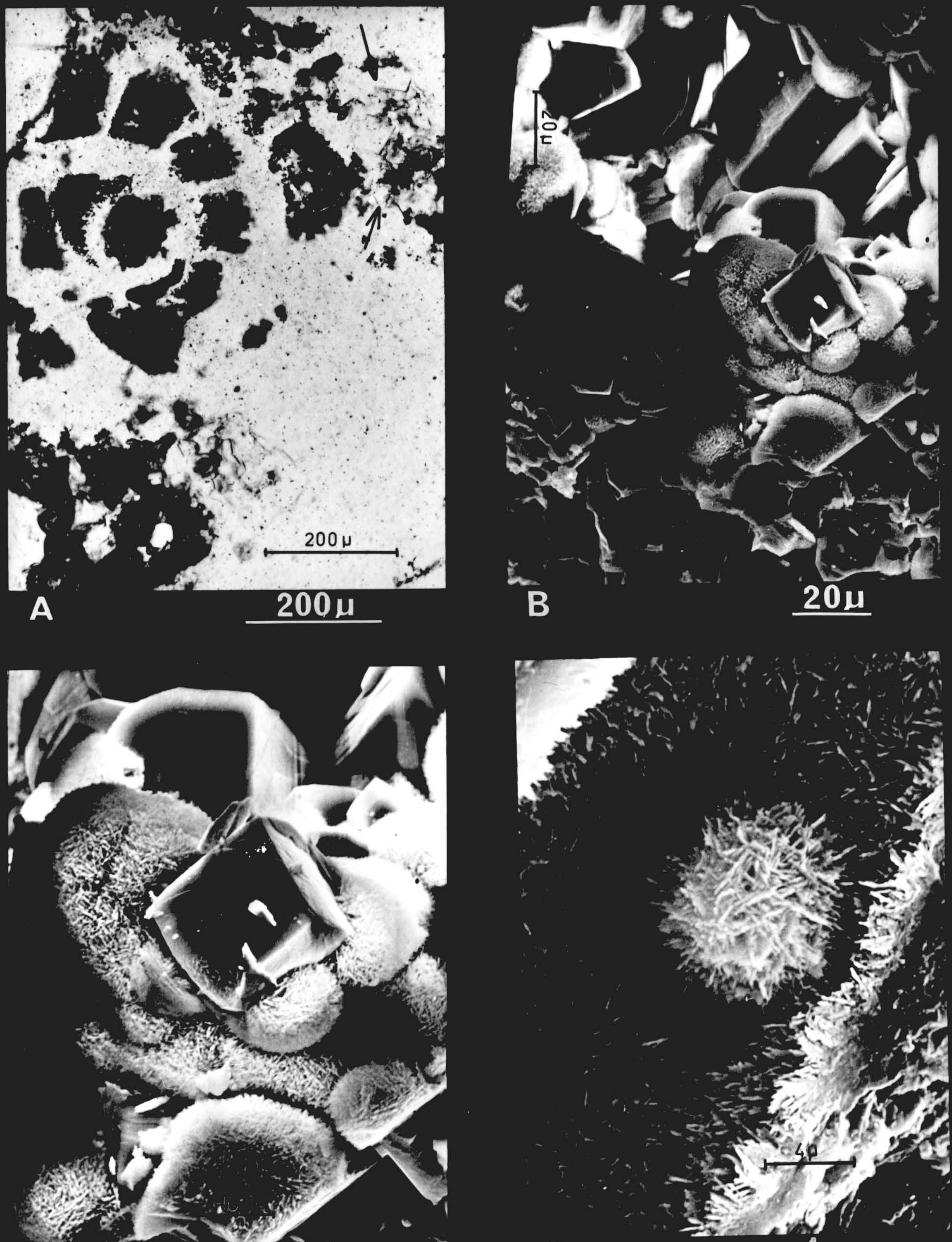


Figure 7/8 Incompletely recrystallized test of Amphistegina (A), which is partially replaced by chalcedony (C). Remnants of internal structure are preserved in the chalcedony. Arrow indicates a dolomite crystal. Foraminifera has stylolitic contact with unidentified fossil fragment in upper right corner. Sample UC 7455 B; plane polarized light; field of view is 2.06 mm.

Plate I (A) Plane polarized light photomicrograph of dolomitized biomicrosparite (sample UC 7467 S) replaced by chalcedony. Outline of foraminifera is clearly visible. Arrows indicate position of dolomite crystals replaced by chalcedony. (B) SEM photomicrograph of cavity in chip of above sample (7467 S). Note spherical crystal aggregates of cristobalite, which post-date formation of dolomite. (C) Close-up of SEM photomicrograph B. (D) SEM photomicrograph showing cristobalite replacement of siliceous(?) sponge spicule. Note the characteristic bladed crystal form of cristobalite. Sample UC 7465 N.

Plate I



<u>Silicification</u> of Nile Group sediments takes three forms: (1) alteration of siliceous sponge spicules to chalcedony; (2) replacement of calcareous allochems and matrix by chalcedony; and (3) bedded porcellanitic cherts.

Quartzose chert, mainly chalcedony, is present in the Glasseye Mudstone, Kongahu Member, and in one Oparara Member sample (sample UC 7454 C). The light brown, translucent chalcedony irregularly replaces parts of allochems, often preserving the internal structures (Fig. 7/8). Less commonly, the alignment of chalcedony crystallites preserves the outline and internal structure of allochems (Fig. 7/9). Irregularly ellipsoidal quartzose chert nodules, up to 0.3 m long, in which chalcedony replaces both matrix and allochems, occur only in calcarenite beds of the Kongahu Member. The botryoidal exterior of the nodules is occasionally visible on weathered surfaces of some beds of the Kongahu Member.

Silicification affects a one meter-thick sequence of Glasseye Mudstone and Kongahu Member fossiliferous, muddy sandstone, which is located at the base of a major channel fill immediately south of Little Wanganui Head (Log 7). The silicified sediments fracture in a conchoidal fashion, and the mudstone has a wax-like luster similar to that of porcellanite. The mudstone (sample UC 7466 W) consists of clay particles in a nearly isotropic medium, which is composed of cristobalite (Fig. 7/10). Silica replacement of the allochems in the porcellanite is rare.

Figure 7/9 Photomicrograph of shell fragment (S) partially replaced by chalcedony (C). Internal fabric and outline of fossil indicated by the orientation of the chalcedony crystallites (dotted lines). Unoriented chalcedony surrounds the shell fragment. Sample UC 7455 M, Gentle Annie Point; crossed polarized light; field of view is 2.60 mm.

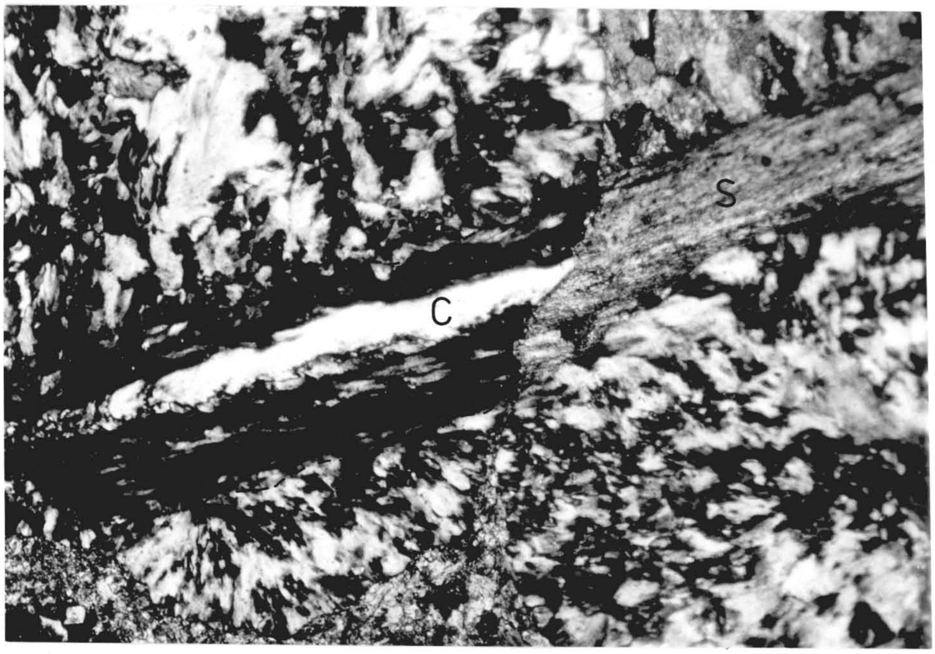
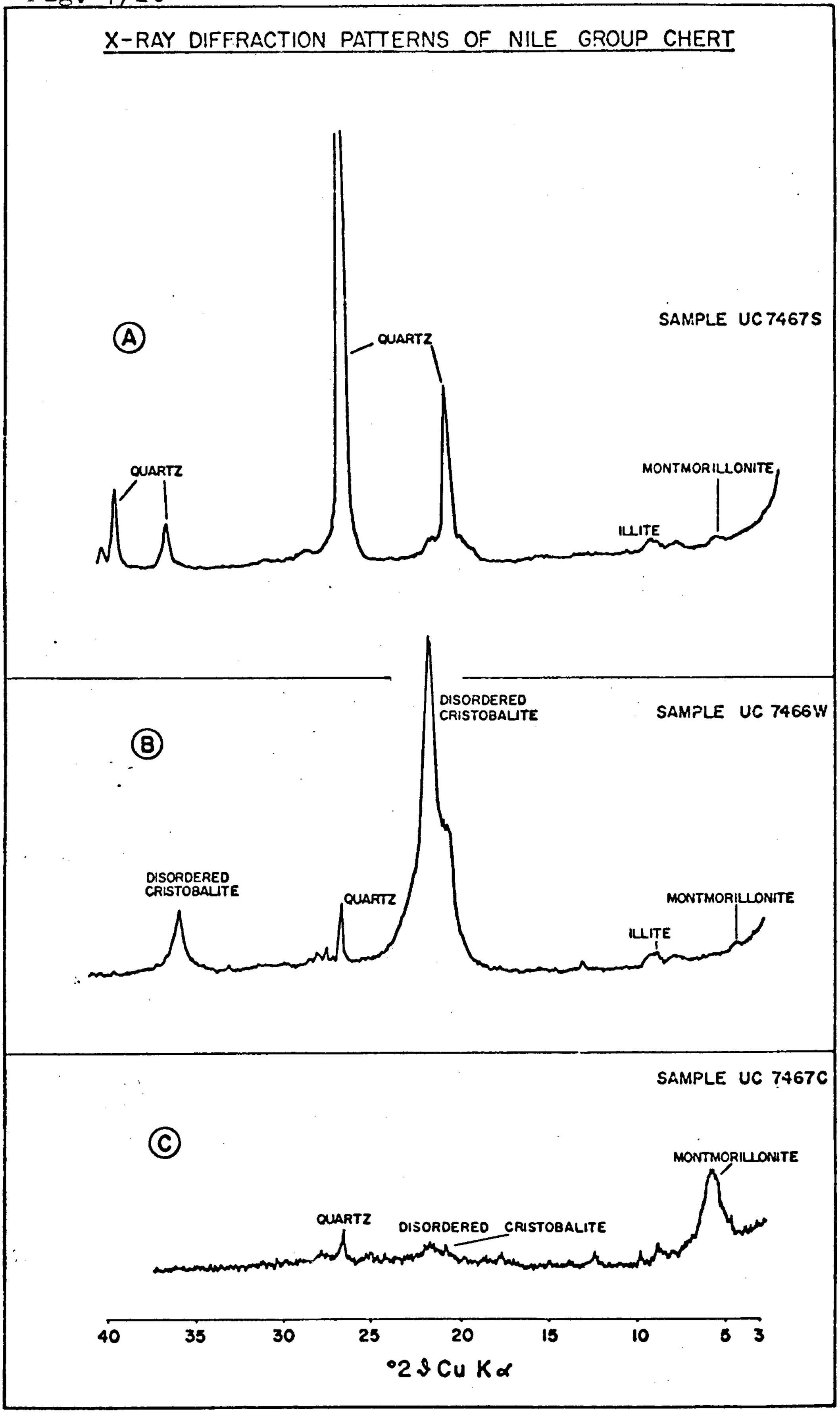


Figure 7/10 X-ray diffraction patterns of typical chert-types within the Nile Group. Calcite was removed by dilute HCl. (A) X-ray diffraction pattern of chalcedony chert nodule (sample UC 7467 S) showing the strong quartz peaks resulting from large chalcedony crystallites. Minor montmorillonite, illite, and detrital quartz is also present. (B) X-ray diffraction pattern of mudstone replaced by porcellanitic chert (UC 7466 W). Note broad peak of disordered cristobalite and minor peaks corresponding to detrital quartz, illite, and montmorillonite. (C) Typical Glasseye Mudstone sample (UC 7467 C) showing broad, flat peak resulting from amorphous silica and disordered cristobalite replacements of sponge spicules, foraminifera, etc. Montmorillonite is the dominant clay mineral.

Fig. 7/10


X-RAY DIFFRACTION PATTERNS OF NILE GROUP CHERT
A
SAMPLE UC 7467S
QUARTZ
QUARTZ
MONTMORILLONITE
ILLITE
B
SAMPLE UC 7466W
DISORDERED CRISTOBALITE
DISORDERED CRISTOBALITE
QUARTZ
MONTMORILLONITE
ILLITE
C
SAMPLE UC 7467C
MONTMORILLONITE
QUARTZ
DISORDERED CRISTOBALITE
40
35
30
25
20
15
10
5
3
°2 ϑ Cu Kα

Lancelot (1973) noted that quartzose chert (chalcedony and quartz) commonly occurs in calcarenites, whereas porcellanitic chert (disordered cristobalite and tridymite) is characteristic of clayey oozes, marls, and marly limestones. Lancelot also commented that the chert in carbonate beds often forms nodules, while the chert in clayey sediments usually forms thin beds and impregnations. Chert types are similarly distributed in the Nile Group. Clayey sediments (like the Glasseye Mudstone) have a low permeability and a ready supply of exchange cations--two factors that encourage the formation of porcellanitic chert (Lancelot, 1973). The higher permeability of calcarenites allows dilution of the exchange cation concentration, which favors the growth of quartzose chert (Lancelot, 1973).

Thin section study suggests the following silicification sequence. Chalcedony first replaces siliceous sponge spicules and large benthonic foraminifera, such as *Amphistegina*. Mollusc and brachiopod fragments are the next allochems to be silicified, followed by echinoderm and bryozoan fragments. Silicification lastly affects carbonate mud and dolomite rhombohedrons.

Silicification is probably an early diagenetic feature (Lancelot, 1973) and can occur in any environment in which free silica is mobilized and made available for chemical precipitation (Weaver and Wise, 1972). Silica precipitation is favored by low pH and temperature conditions and by the saturation of pore solutions by silica (Fairbridge, 1967). Siliceous sponge spicules, radiolaria, and diatoms probably provided most of the silica; calcitization of feldspars may have contributed some. Pressure solution of quartz and feldspar grains is rare in the sequence, and was probably unimportant as a source of silica.

Silicified allochems are not deformed in any way and often retain traces of the original internal structure. This implies that replacement proceeded without void space production and was accomplished by a thin water film (cf., Scholle, 1971).

Scanning electron microscopy of chips of Glasseye Mudstone reveals that numerous foraminifera tests and sponge spicules contain spheres and crusts of a fine bladed mineral, which fits the description of cristobalite (see Weaver and Wise, 1972) and corresponds with SEM photomicrographs of cristobalite (Lancelot, 1973). Representative SEM photomicrographs are shown in Plate 1.

Mitzutani (1970) noted that the presence of amorphous silica and chert within a sediment indicates that only low-temperature diagenesis took place.

Calcite replacement of siliceous organisms, such as sponge spicules and radiolaria, is a common diagenetic feature. The dissolution of silica and replacement by calcite probably occurred simultaneously, since no evidence of void space production was found, and internal structures, including the central canals of sponge spicules, are preserved. The mechanism by which silica can be dissolved and calcite precipitated in its place is in doubt, although Scholle (1971) suggested that organic sheaths on the particles provided the necessary microenvironments and acted as templates for the replacing mineral. The replacement of siliceous organisms by calcite probably took place in a moderately high pH environment during the early(?) stages of diagenesis.

Feldspar alteration, including sericitization, vacuolization and replacement by calcite, is widespread, but it is most common in the feldspathic Kongahu Member. Orthoclase appears to be most prone to sericitization. Calcite patchily replaces all feldspar types, especially microcline (Fig.7/11). Vacuolization affects all types.

Calcitization of feldspars occurred *in situ*. Some calcite replacements are continuous with the cement surrounding the feldspar grain. The calcitization of feldspar probably required a moderately high pH environment. The time of replacement is in doubt.

Numerous examples of differential pressure solution are encountered in Nile Group sediments; the effects are most common in the limestones and are almost absent in the Glasseye Mudstone. Embayed and stylolitic contacts between allochems are the most common evidence of pressure solution (Fig. 7/8). Frequently detrital grains are deeply embedded within fossil fragments. Microstylolites sporadically occur in the limestones of the study area, particularly in the Stony Creek Limestone. The microstylolites appear as irregular, iron stained, argillaceous partings in the rock. The formation of

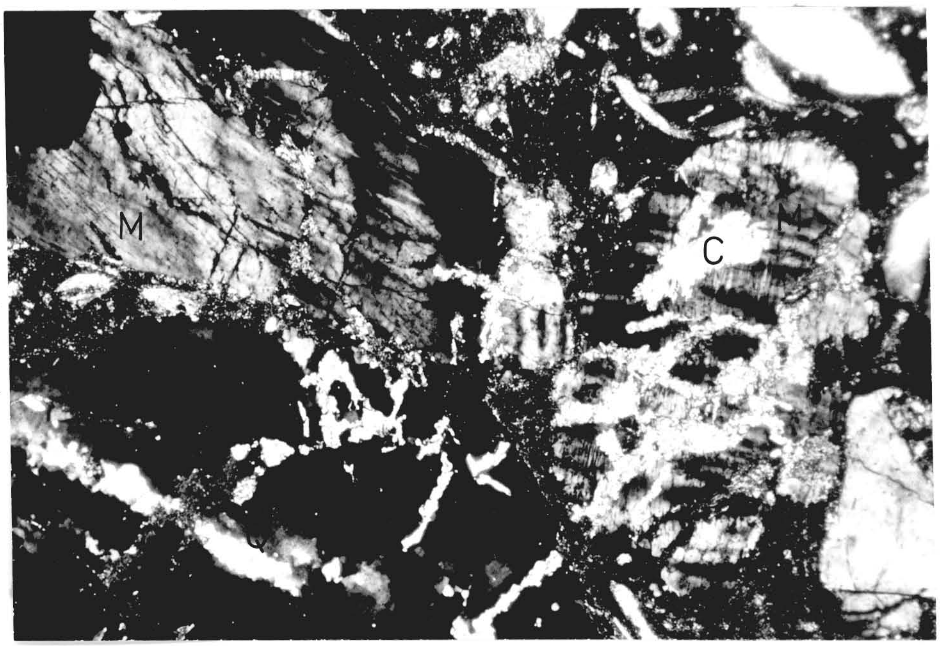
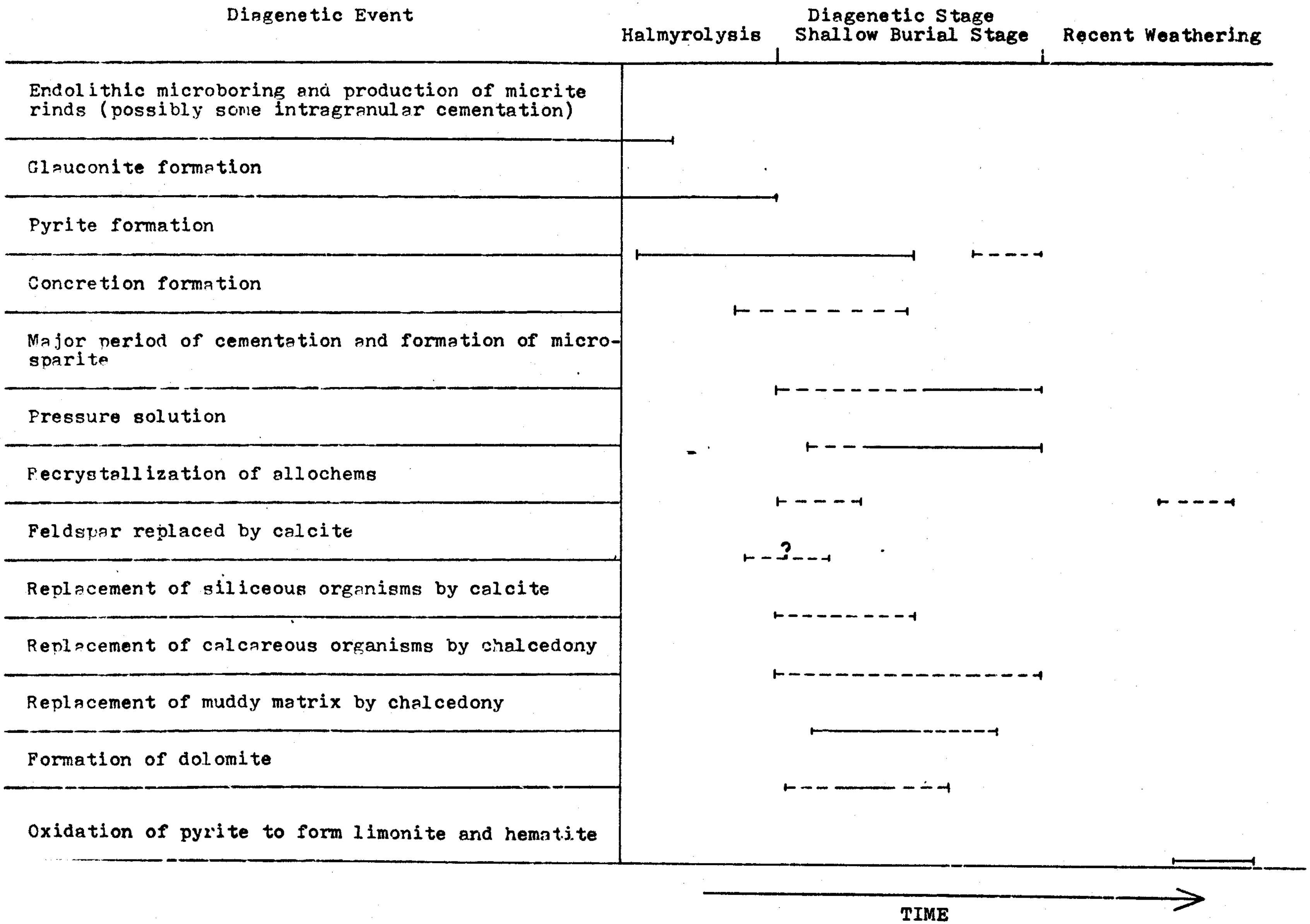


Figure 7/11 Photomicrograph showing microcline (M) partly replaced by calcite (C) (light colored patches in microcline); quartz (Q) and microcline in micrite matrix. Crossed polarized light; sample UC 7458 K; field of view is 2.07 mm.

embayed and stylolitic intergranular contacts and microstylolites results in a significant reduction of the volume and original pore space of the rock. Pressure solution provides large amounts of calcium carbonate, which is utilized during cementation. Little is known about the depth of burial required to initiate pressure solution, but a minimum figure would be about 90 m (Bathurst, 1971).

Table 7/7 presents a generalized paragenetic sequence for the Nile Group.

TABLE 7/7 SCHEMATICIZED PARAGENETIC SEQUENCE OF THE NILE GROUP



CHAPTER 8

INTERPRETATIONS

TECTONIC PATTERNS

The Paparoa Tectonic Zone has greatly influenced the tectonic patterns of southwest Nelson (Laird, 1968). Laird traced this tectonic zone along the West Coast from south of Hokitika to Kongahu Point. According to Laird, a tensional stress regime caused normal faulting and subsidence, which created a series of elongated, NNE-trending basins. Basin formation began in the Greymouth area in the late Cretaceous and, following the course of the Paparoa Tectonic Zone, spread to the Granity region by the late Eocene (Laird and Hope, 1968) (Fig. 8/1). Great thicknesses of sediment accumulated in these depressions during early and mid Tertiary times. A small NNE-trending basin developed near Granity in the late Eocene (Laird and Hope, 1968). The source area for the detritals that were supplied to this basin was " ... a ridge of high land consisting mainly of granite, gneiss and schist which lay to the immediate west of the present shoreline in Upper Kaiatan times, the fossil coast probably being represented by a scarp facing the present coast, at least in the vicinity of Granity and Ngakawau ... " (Laird and Hope, 1968, p. 430). Sedimentation rates in the area slowed by late Eocene times, as the offshore source area was reduced to base level.

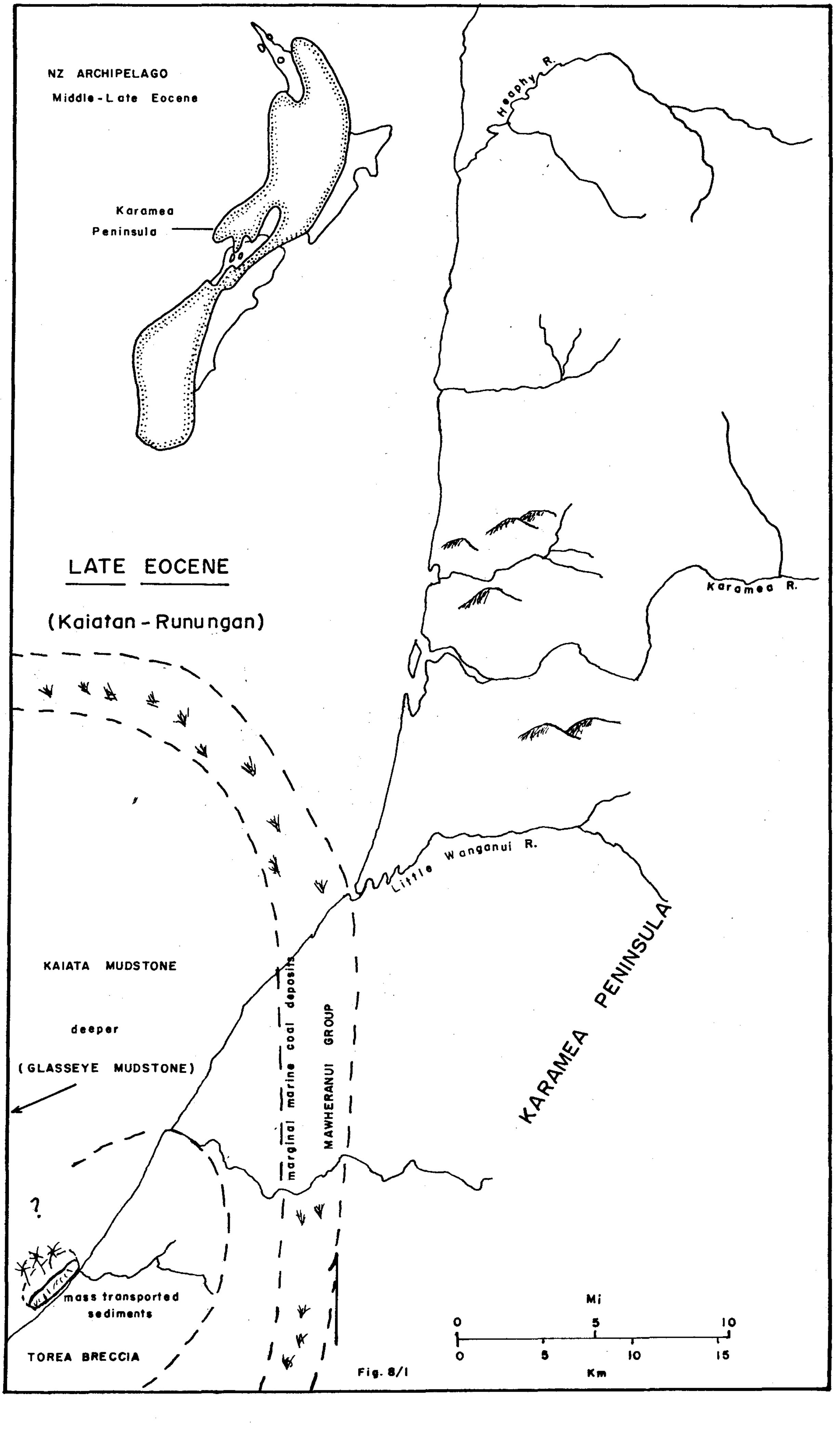

NZ ARCHIPELAGO
Middle-Late Eocene
Karamea
Peninsula
Heaphy R.
LATE EOCENE
(Kaiatan - Runungan)
Karamea R.
Little Wanganui R.
KARAMEA PENINSULA
KAIATA MUDSTONE
deeper
(GLASSEYE MUDSTONE)
marginal marine coal deposits
MAWHERANUI GROUP
?
mass transported
sediments
TOREA BRECCIA
Mi
0 5 10
0 5 10 15
Km

Fig. 8/1

The Kongahu Member and Glasseye Mudstone represent sedimentation in a northern extension of the Paparoa Tectonic Zone. In the early Oligocene, the site of normal faulting and basin subsidence shifted about 10 km northwards to the area between the Mokihinui and Little Wanganui Rivers. Normal faulting created a small landmass or series of islands immediately west of the present coastline. The abundance of land plant remains and possible pedalogical features (Chap. 6) in the Kongahu Member supports the hypothesis that the source of the Kongahu Member was emergent and was not a submarine high. Whaingaroan breccias and conglomerates of the Kongahu Member suggest that the landmass initially had a rugged relief. The Kongahu Member-Glasseye Mudstone basin occupied the southern half of the study area as far north as Limestone Creek (Figs. 8/2 and 8/3). The absence of Kongahu Member conglomerates and breccias in the Karamea-Kohaihai Bluff area may indicate either that the western landmass did not extend northwards beyond Little Wanganui, or that the sediments which were derived from the west were channelled elsewhere, by-passing the Karamea area. In any event, the Karamea region was probably situated on a stable platform, which was not strongly affected by Paparoa Tectonic Zone activity. Only one minor late Duntroonian to Waitakian unconformity is noticeable in the sediments of the Karamea region. Sedimentation in the Little Wanganui area basin continued without interruption until late Waitakian time, when much of the

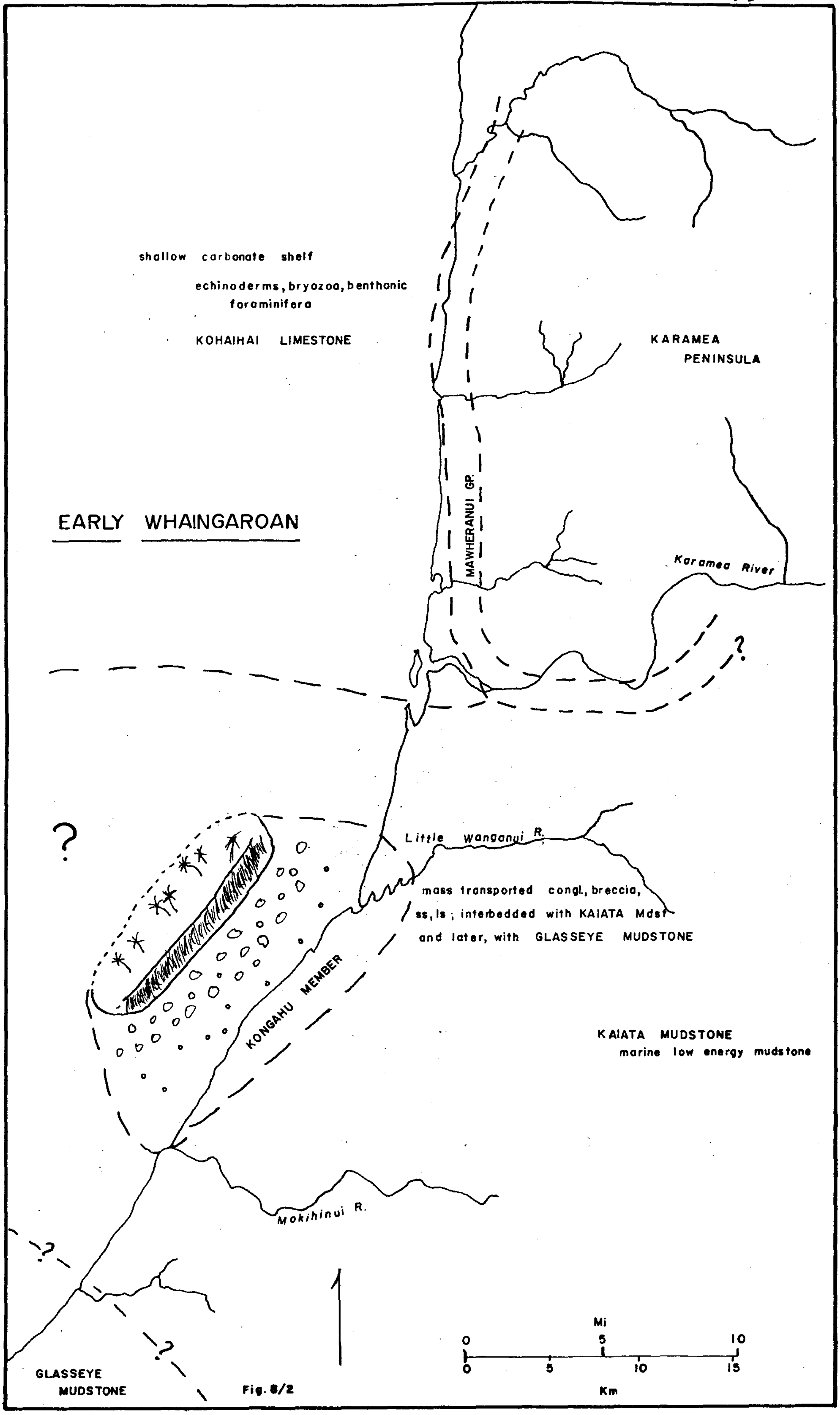

shallow carbonate shelf
echinoderms, bryozoa, benthonic foraminifera
KOHAIHAI LIMESTONE
KARAMEA PENINSULA
MAWHERANUI GP.
EARLY WHAINGAROAN
Karamea River
?
?
Little Wanganui R.
mass transported congl., breccia, ss, ls ; interbedded with KAIATA Mdst and later, with GLASSEYE MUDSTONE
KONGAHU MEMBER
KAIATA MUDSTONE
marine low energy mudstone
Mokihinui R.
?
?
Mi
0
5
10
0
5
10
15
Km
GLASSEYE MUDSTONE

Fig. 8/2

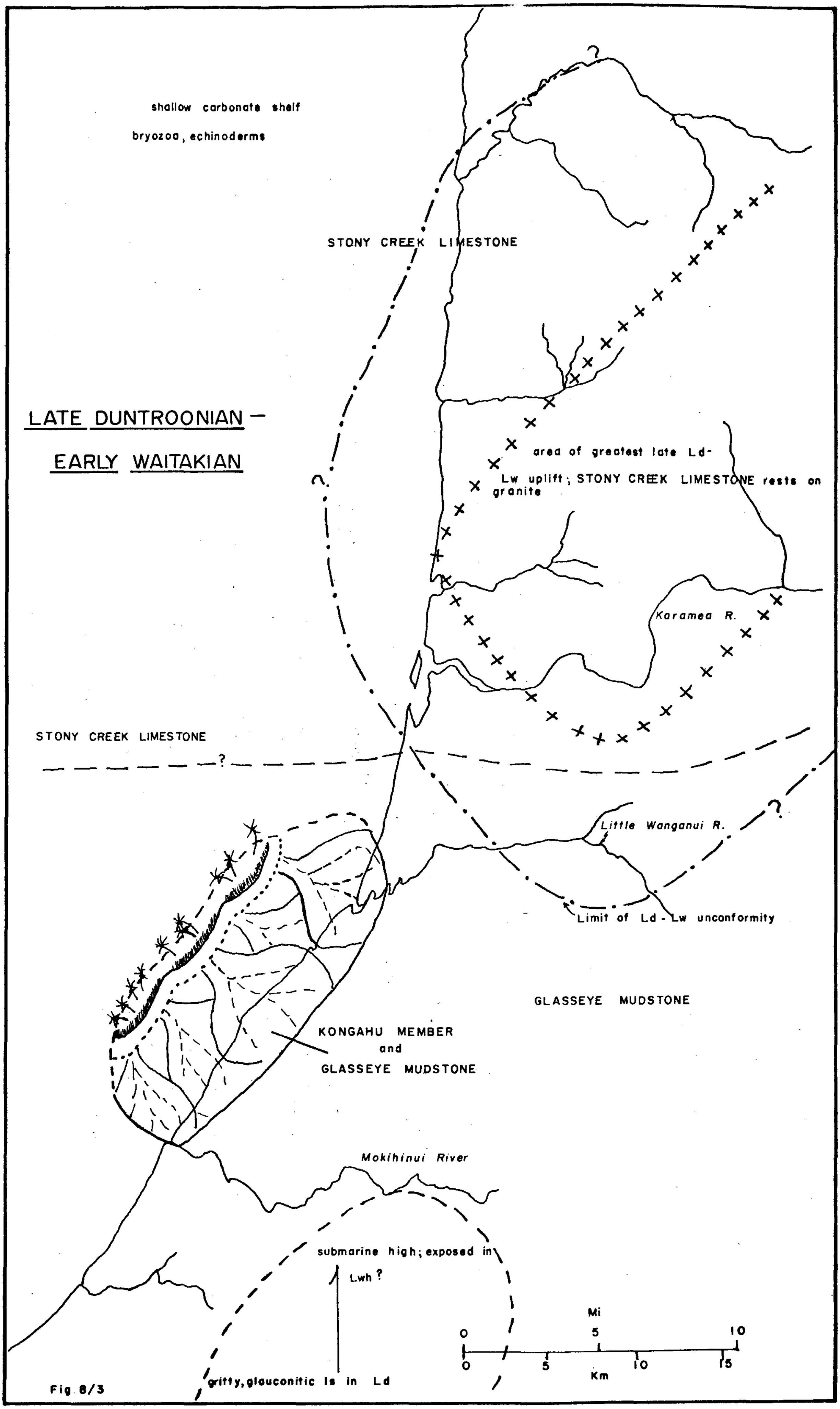

shallow carbonate shelf
bryozoa, echinoderms
STONY CREEK LIMESTONE
LATE DUNTROONIAN –
EARLY WAITAKIAN
area of greatest late Ld-Lw uplift; STONY CREEK LIMESTONE rests on granite
Karamea R.
STONY CREEK LIMESTONE
Little Wanganui R.
Limit of Ld - Lw unconformity
GLASSEYE MUDSTONE
KONGAHU MEMBER
and
GLASSEYE MUDSTONE
Mokihinui River
submarine high; exposed in
Lwh ?
gritty, glauconitic ls in Ld
Mi
0
5
10
0
5
10
15
Km

Fig 8/3

southwest Nelson-northern Buller area was uplifted (Fig. 8/3). The unconformity near Happy Valley Saddle between the Oparara Member and the Glasseye Mudstone is a result of this uplift (Logs 7 and 9).

According to Laird (1968), the tensional stress regime along the Paparoa Tectonic Zone altered to a regime of thrusting to the WNW during the early Miocene. The change in stress resulted in the development of monoclines, overfolds, and reverse faults in the late Tertiary and Quaternary. The late Tertiary monoclines near Granity (Laird, 1968) and the overturning of strata at Gentle Annie Point are examples of the structures produced. Movement along the View Hill Fault took place during the Kaikoura Orogeny. The present rugged coastline may be the result of movement along the Kongahu Fault during the same period.

PALEOGEOGRAPHIC HISTORY

Fleming (1962) inferred that a large landmass--termed the Karamea Peninsula--existed over all but the southwest part of the study area (Fig. 8/1) during the Eocene. The coal-bearing Mawheranui Group probably accumulated on lowland flood plains, which covered much of the Karamea Peninsula. The thickness of the unit (Logs 1 and 2) suggests that the Karamea Peninsula was relatively stable during the late Eocene-early Oligocene. Along Highway 67, the marine Kaiata Mudstone overlies the Mawheranui Group. The Kaiata Mudstone represents the earliest marine sediment in the study area. These sediments were deposited during the northward-moving transgression that began in the Greymouth area during the Eocene (Fleming, 1975). By early Whaingaroan time, the transgression had reached the Karamea region. The marine Kohaihai Limestone overlies the Mawheranui Group at Kohaihai Bluff and Stony Creek. The transgression reached its climax in Waitakian time, when virtually all of the Karamea Peninsula (and all of the study area) was submerged.

Several lines of evidence suggest that a western landmass existed during Whaingaroan to Waitakian time. The most significant evidence is the distribution of the breccias and conglomerates of the Kongahu Member. The geological map (back pocket), Figure 8/2, and Logs 5-8 reveal that the Kongahu Member is largely confined to the coast between Gentle Annie Point and Little Wanganui Head. The Kongahu Member crops out inland along Highway 67, but there the beds are less numerous, thinner, and finer grained than those along the coast. The coastal beds often contain enormous granite boulders up to 10 m diameter. The boulders must have been deposited relatively close to their source. Commonly exposed on the base of the Kongahu Member beds are groove casts, which trend roughly E-W (Fig. 4/25). Groove casts, which contain <u>in situ</u> tools, mark the base of a Kongahu Member bed at Gentle Annie Point (Figs. 4/22-4/24). The position of the <u>in situ</u> tools suggests that the Kongahu Member was emplaced from the northwest.

The CMo diagrams (Fig. 5/1) provide less direct evidence for the presence of a western landmass. The coastal mudstone province (Glasseye Mudstone) contains coarser sediments than its inland counterpart. This may be due to: (1) closer proximity to a western source area; or (2) greater availability of coarse beds that were mixed with Glasseye Mudstone by slumping and burrowing.

The DAM diagram of the Glasseye Mudstone and Kongahu Member (Fig. 6/1b) shows that the inland mudstone contains a lower percentage of allochems than the coastal mudstone. Burrowing probably introduced many of these allochems into the mudstone from the Kongahu Member; a low allochem percentage in the Glasseye Mudstone occurs where few Kongahu Member beds are present. The diagram also shows a very crude tendency for inland beds of the Kongahu Member to contain more mud and fewer allochems than their coastal counterparts.

The landmass probably emerged at the beginning of the Oligocene. The lowest Kongahu Member at Kongahu Point, which is tentatively dated as early Whaingaroan, probably (slightly) post-dates the emergence of the source. The landmass probably consisted of a rugged granitic island or group of islands, which had a cliffed eastern shoreline. The rock fragments in the Kongahu Member, which are granitic or gneissic, were probably derived from the Paparoa Granite and its metamorphic phases. The wide size range and angularity of detrital clasts and the proportions of sizes present in the Kongahu

Member imply that the sediment originally accumulated at the base of granite cliffs prior to final deposition in deeper water. Webb (1910) and Wellman (unpubl.) also suggested that the sediment of the Kongahu Member spalled off granite cliffs.

Transgression continued onto the Karamea Peninsula during Whaingaroan to Waitakian time (Figs. 8/1-8/3). By Waitakian time most of the northern half of the South Island was submerged; Miocene or Pliocene uplift exposed land areas to the east of the study area (Fleming, 1962). A local uplift occurred in the Karamea region during late Duntroonian-early Waitakian times (Fig. 8/3). The previously deposited Kohaihai Limestone and undifferentiated Mawheranui Group were eroded from much of the area (Logs 1-4). Evidence indicating subaerial exposure of the uplifted area is lacking. Wellman (unpubl.) suggested that submarine erosion removed much of the sediment cover on a submarine high and caused the minor unconformity. More data are required before the exact origin of the unconformity can be determined.

Sedimentation continued without apparent interruption during Landon time in the southern half of the study area (Figs. 8/3 and 8/4). Beds of the Kongahu Member are present throughout the lower part of the coastal sequence, but become thinner, more scarce, and finer grained in the upper 85 m of the sequence at Little Wanganui Head. Kongahu Member sediments are virtually absent from the upper 29 m of the Little Wanganui Formation at Little Wanganui Head (Log 7). The absence of

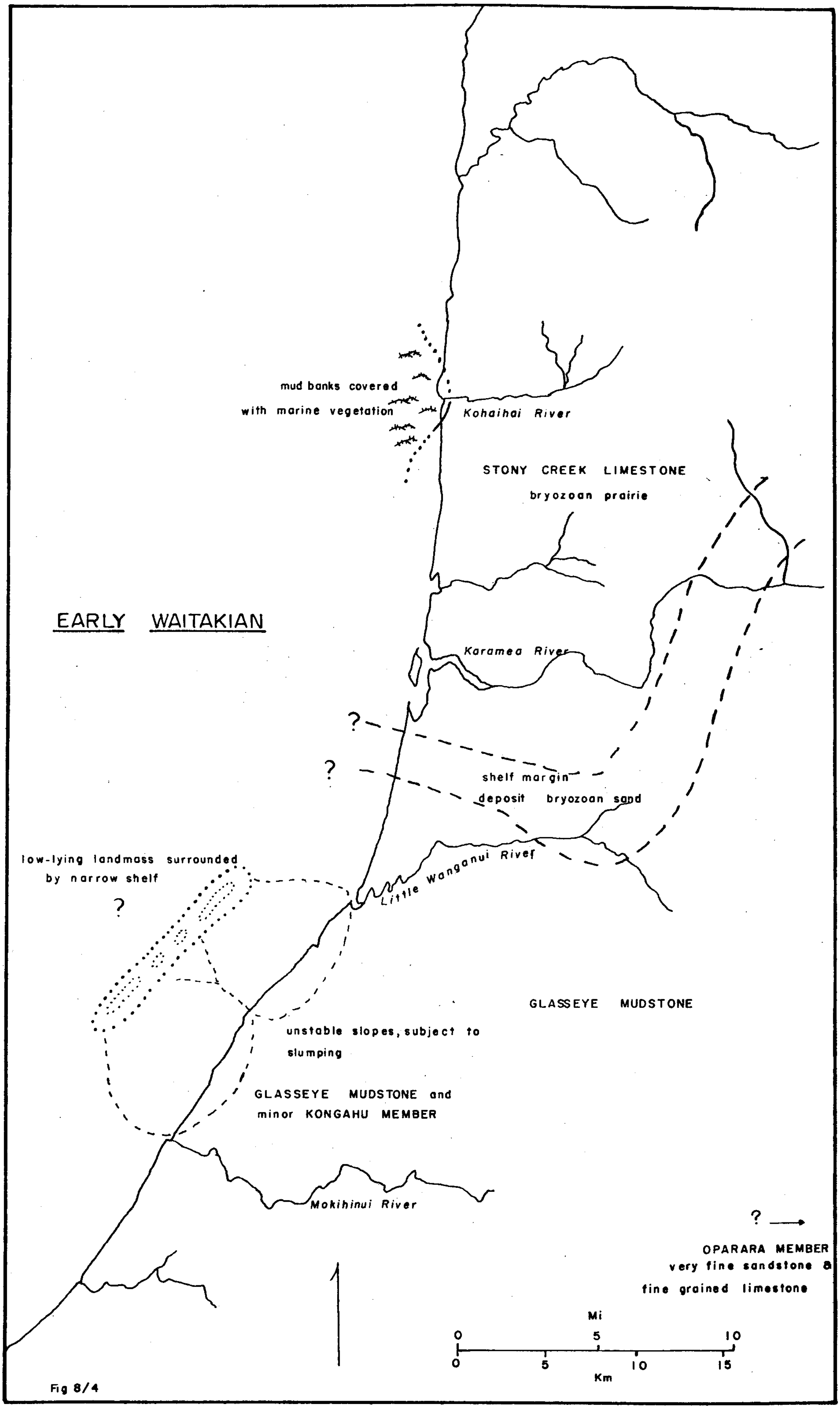

EARLY WAITAKIAN
mud banks covered
with marine vegetation
Kohaihai River
STONY CREEK LIMESTONE
bryozoan prairie
Karamea River
?
?
shelf margin
deposit bryozoan sand
low-lying landmass surrounded
by narrow shelf
?
Little Wanganui River
GLASSEYE MUDSTONE
unstable slopes, subject to
slumping
GLASSEYE MUDSTONE and
minor KONGAHU MEMBER
Mokihinui River
?
OPARARA MEMBER
very fine sandstone &
fine grained limestone
Mi
0
5
10
0
5
10
15
Km

Fig 8/4

Kongahu Member sediments in the upper part of the sequence implies that the sediment supply from the western source area was reduced in late Landon time or that sediment that was derived from the source area by-passed the Little Wanganui area (Fig. 8/4). A decrease in sediment supply from the source area may be related to a reduction in the relief of the western landmass. A lessening of relief reduced the supply of large granite clasts and restricted the areal occurrence of the gravelly sandstone textural group (Chap. 5). A further reduction in relief, perhaps to base level, caused the cessation of coarse sedimentation in the Little Wanganui area. The western landmass was probably submerged by Waitakian time.

The coastal section south of Little Wanganui contains abundant evidence of slumping. Slumping is limited to the lower portions of the section along Highway 67. This distribution of slumping may reflect differences in depositional conditions during Landon time. The inland areas may have had lower sedimentation rates, lower slope angles, and less severe tectonic shocks.

A major uplift occurred in the southwest Nelson-northern Buller region in late Oligocene time (Fig. 8/5). The uplift did not affect the northern half of the study area, but at Glasseye Creek and near Happy Valley Saddle the Oparara Member rests unconformably on the Glasseye Mudstone. No evidence was found to determine whether the erosion was submarine or subaerial. The bimodal

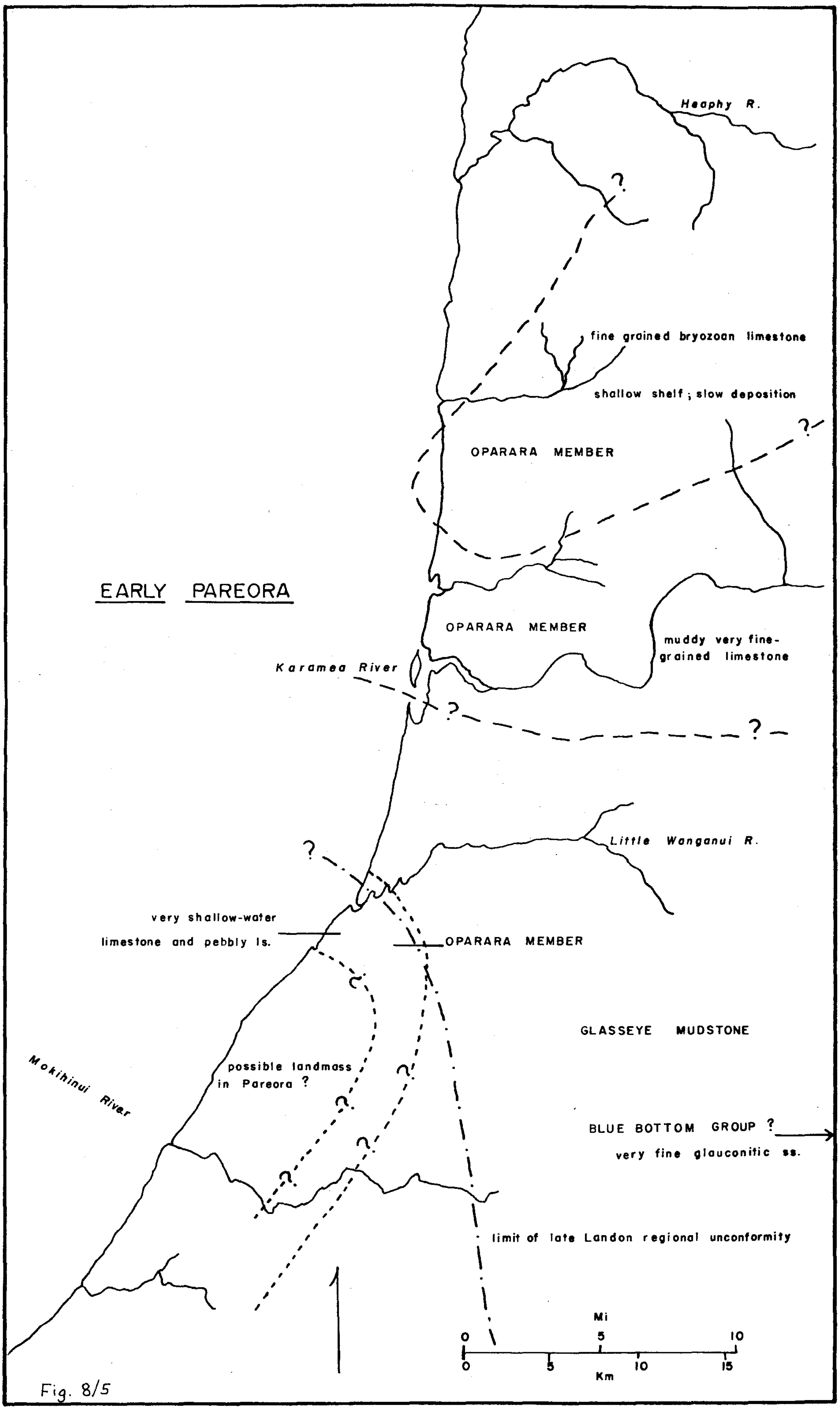

Heaphy R.
fine grained bryozoan limestone
shallow shelf; slow deposition
OPARARA MEMBER
EARLY PAREORA
OPARARA MEMBER
muddy very fine-grained limestone
Karamea River
Little Wanganui R.
very shallow-water limestone and pebbly ls.
OPARARA MEMBER
GLASSEYE MUDSTONE
possible landmass in Pareora ?
Mokihinui River
BLUE BOTTOM GROUP ?
very fine glauconitic ss.
limit of late Landon regional unconformity
Mi
0
5
10
0
5
10
15
Km

Fig. 8/5

size distribution and coarse clastic content of the sparite-cemented Oparara Member may represent a lag deposit of Kongahu Member sediments, which were reworked in a high energy environment.

The widespread occurrence of the Blue Bottom Group implies that the entire region was completely submerged during the early Miocene.

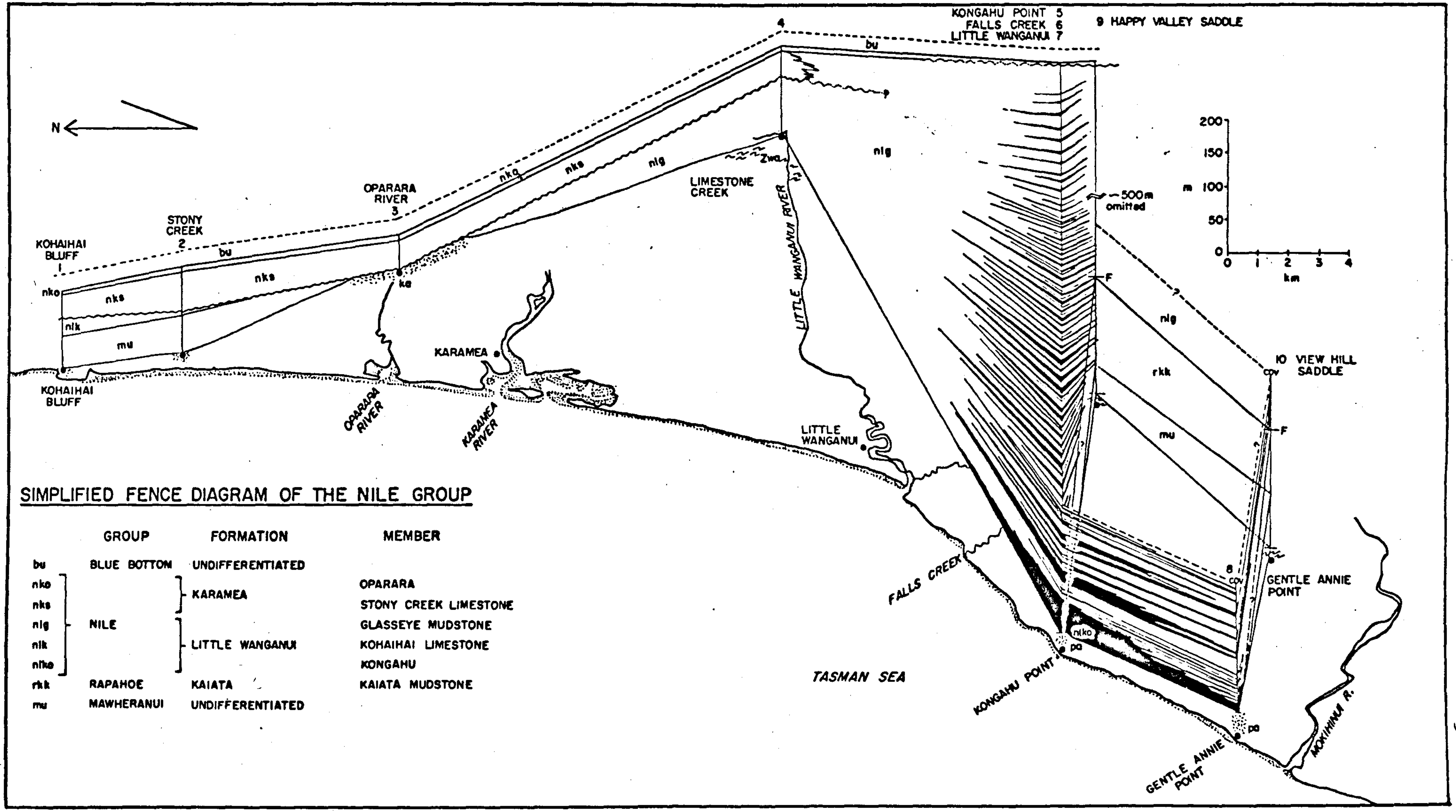
The fence diagram (8/6) shows the distribution and lateral and vertical relationships of the members of the Nile Group.

Depth Considerations

The predominance of pelagic foraminifera in the Kaiata Mudstone suggests that the sediment accumulated in open marine conditions.

The Kohaihai Limestone contains numerous benthonic foraminifera, including *Amphistegina*, which are given a maximum depth range of 175 m by Hornibrook (1968). Solitary corals are also common in the member. Modern solitary corals require well oxygenated water, between 11° and 40° C; they have a wide depth tolerance, but thrive in waters about 100 m deep with a mean temperature of about 20° C (Milliman, 1974). Bryozoa are common in the upper portion of the member. Modern bryozoa have wide depth ranges but occur most densely in shallow shelf waters 20-80 m deep (Ryland, 1967, cited by Milliman, 1974). The lowest Kohaihai Limestone deposits are probably littoral; depositional depths increased for the

Fig. 8/6


SIMPLIFIED FENCE DIAGRAM OF THE NILE GROUP
N
KOHAIHAI BLUFF 1
STONY CREEK 2
OPARARA RIVER 3
4
KONGAHU POINT 5
FALLS CREEK 6
LITTLE WANGANUI 7
9 HAPPY VALLEY SADDLE
10 VIEW HILL SADDLE
8
GENTLE ANNIE POINT
LIMESTONE CREEK
LITTLE WANGANUI RIVER
KARAMEA
OPARARA RIVER
KARAMEA RIVER
LITTLE WANGANUI
FALLS CREEK
TASMAN SEA
KONGAHU POINT
GENTLE ANNIE POINT
MOKIHINUI R.
KOHAIHAI BLUFF
~500m omitted
m
200
150
100
50
0
0 1 2 3 4
km
bu
nko
nks
nlg
nlk
mu
ke
Zwa
rkk
F
cov
pa
nlko
GROUP
FORMATION
MEMBER
bu BLUE BOTTOM UNDIFFERENTIATED
nko OPARARA
nks KARAMEA STONY CREEK LIMESTONE
nlg NILE GLASSEYE MUDSTONE
nlk LITTLE WANGANUI KOHAIHAI LIMESTONE
nlko KONGAHU
rkk RAPAHOE KAIATA KAIATA MUDSTONE
mu MAWHERANUI UNDIFFERENTIATED

remainder of the unit, reaching a maximum in Duntroonian time (perhaps as much as 175 m). A shallowing probably preceeded development of the late Duntroonian unconformity, when the depth was perhaps 20-80 m or less.

The Stony Creek Limestone is largely composed of bryozoan fragments with subsidiary amounts of *Amphistegina* (see above), molluscs, and serpulid worm tubes. The molluscan fauna at Kohaihai Bluff (Table 6/6) suggests a shallow marine environment of deposition; *Glycymeris*, *Limatula*, *Dosinia*, and *Chlamys*, all occur today in the offshore New Zealand sediments (Morton and Miller, 1973). Serpulid worms require shallow, agitated conditions for maximum growth (Milliman, 1974). The Stony Creek Limestone probably accumulated within the range of most vigorous modern bryozoan growth, that is 20-80 m.

The Glasseye Mudstone contains numerous *Zoophycus* ichnofossils, which Seilacher (1967) considered to be characteristic of sediments deposited below wave base. Planktonic foraminifera are the dominant allochems and are typical of modern oceanic sediments from depths less than 4000-5000 m (Milliman, 1974). Benthonic foraminifera are also present in the mudstone but appear to be mainly introduced from beds of the Kongahu Member by burrowing. Siliceous sponge spicules occur in all mudstone samples and, next to foraminifera, are the dominant allochems. Tasch (1973) stated that siliceous sponges flourish in depths of around 300 m, although many siliceous sponges have been dredged from Indonesian waters in depths of about 150 m. The sparcity of red algal fragments and of allochems with algal microborings may indicate that the mudstone accumulated at the lower limit of or below the photic zone. The depth of accumulation for the Glasseye Mudstone is estimated to be 150-300 m, or at least below wave base (and possibly below the photic zone).

The Kongahu Member contains numerous echinoderm fragments, which are usually concentrated in shallow shelf environments (Milliman, 1974). Red algae, bryozoa, Amphistegina, and siliceous sponge spicules are the other major allochems (Table 6/7, and discussion above). Rhodolites are abundant throughout the member. Adey and Macintyre (1973) noted that modern rhodolites can form in clear tropical waters in depths of 50-200 m. Rhodolite formation is largely dependent on wave action; conditions that are too stormy prevent rhodolite formation and a very low energy environment would allow the growth of coalescing crusts. The majority of the allochems in the Kongahu Member probably lived in depths of 20-200 m. Mass transport mechanisms (see below) eventually deposited the allochems in the deeper Glasseye Mudstone environment.

The allochem assemblage of the Oparara Member (Table 6/5 and discussion above), the presence of glauconite (Chap. 6), and intense algal microboring indicate that the sediment accumulated in a shallow marine environment, well within the photic zone. The presence of numerous pelagic foraminifera at Limestone Creek (Chap. 3 and Log 4) suggests that the region was slightly deeper, perhaps as deep as the Glasseye Mudstone environment (about 150-300 m).

PALEOENVIRONMENTS

The Mawheranui Group represents the earliest Tertiary sediments in the northern part of the study area and overlies weathered Karamea Granite in the Karamea area. The sediments probably accumulated on lowland flood plains, which bordered the western sea (Fig. 8/1 and 8/2). Terrestrial plant remains are the dominant fossils and imply that the Karamea Peninsula was vegetated. The organic material probably accumulated in small swamps or depressions. At Kohaihai Bluff, (Log 1) coaly laminations are interbedded with calcareous sediments, suggesting that some organic deposition occurred under marginal marine conditions. The presence of coarse sand and pebbles in the coaly, very fine grained sediment suggests that the generally low-energy basins received some high-energy influxes of sediment, possibly during flooding.

The Kaiata Formation (Kaiata Mudstone) conformably(?) overlies the Mawheranui Group near Corbyvale (Chap. 3, descriptions of Logs 9 and 10) and is widespread south of the study area.

Rare parallel continuous laminations suggest that the sediment accumulated under low energy conditions, probably by the slow settling of suspended particles. The scarcity of primary sedimentary structures and the presence of poorly preserved trace fossils indicate that bioturbation was widespread, and by inference, that the sediment accumulated in a generally oxidizing environment. The increasing carbonate content in the upper half of the formation suggests a lessening of mud influx, possibly due to the continuing transgression and progressive isolation of land areas. The Kaiata Mudstone facies shifted to the NNE during the early Oligocene in response to the continuing Eocene-Oligocene transgression. The seaward(?) Glasseye Mudstone facies shifted into the Little Wanganui region as water depths increased during the Oligocene (Figs. 8/1 and 8/2). Mudstone deposition did not occur in the Karamea region, which was apparently situated on a relatively shallow carbonate shelf.

The Kohaihai Limestone conformably overlies the Mawheranui Group in the Karamea region. The lower 12 m of the member, which is slightly calcareous and contains many discontinuous coaly laminations, probably represent a marginal marine environment. The poor sorting and micritic matrix of the sediment indicate that it was deposited in a low energy environment. The presence of glauconite, solitary corals, and *Amphistegina* in the upper portion of the member signifies that the sediment accumulated slowly in warm, shallow waters (Chaps. 6 and 8, Depth Considerations). The member is highly calcareous and fossiliferous in its upper part, indicating open marine conditions, which are the result of continuing transgression. The generally well sorted, mud-free character of the upper part of the member supports the contention that moderate to strong current conditions became predominant during late Whaingaroan and Duntroonian time. Thin sections reveal that echinoderm fragments are the most common allochem constituent. The presence of faint tabular cross bedding at Kohaihai Bluff (Log 1) suggests that the sediment possibly accumulated as dunes of coarse carbonate sand in a high energy environment (probably shallow). An increase in bryozoan content in the upper few meters of the member suggests a shallowing of the seas, probably preceeding the formation of the middle Oligocene unconformity. Local uplift caused a period of nondeposition and erosion at the end of Duntroonian or beginning of Waitakian time. The absence of the unit at Oparara River (Chap. 3, Log 2) and the presence of nodular and bored(?) zones at the top of the Kohaihai Limestone at Kohaihai Bluff and Limestone Creek (Chap 3 , Logs 1 and 4) support the uplift hypothesis. Figure 8/3 illustrates the extent of the uplift, which was limited to the northern half of the study area. To the south, deposition of the Glasseye Mudstone and Kongahu Member continued without apparent interruption.

Deposition of the Stony Creek Limestone probably began early in Waitakian time and marked the renewed subsidence. At Oparara River and Stony Creek the lower portion of the member contains numerous pebbles, which were derived either directly from the Paparoa Granite or from reworked portions of the Kohaihai Limestone and Mawheranui Group. The overall detrital content decreases rapidly upwards from the base, but local concentrations of sand and fine pebbles frequently mark the wavy bedding planes in the lower two-thirds of the member. The decrease in detrital content may reflect the renewed subsidence and the progressive isolation of that local source area, which possibly lay northeast of the study area. The scattered concentrations of sand along the bedding planes may signify that sediment was transported to the deeper portions of the shelf by the surge of storm waves.

The typical lithology of the Stony Creek Limestone is a clean to moderately well washed biosparite indicative of a moderate to high energy environment of deposition. The presence of microsparite in some samples suggests entrapment of fine material. A biomicrudite represents the member at Kohaihai Bluff. This anomalous lithology, which accumulated in situ, could represent a local low energy depositional environment, or it may be the result of current baffling by marine plants, such as Thalassia; the Thalassia-covered mud mounds in Florida Bay may be modern analogues (Bathurst, 1971).

Bryozoan fragments are the dominant biotic constituents of the Stony Creek Limestone. The bryozoan zoaria are often stick-like fragments up to several centimeters long or larger hemispherical to cylindrical masses, frequently with a hollow or sparite-filled central canal. The hemispherical and cylindrical zoarial types closely resemble Recent zoaria from the Bahamas (Hoffmeister, Stockman, and Multer, 1967). The Bahamian bryozoa encrust marine grasses and gorgonians and acquire a knobbly or cylindrical shape. Decomposition of the encrusted substrate leaves a hollow center, which is usually filled by mud. The Bahamian bryozoa flourish in warm waters, 12-15 feet deep (Hoffmeister, et al., 1967). A modern bryozoan environment possibly more in keeping with the New Zealand Landon situation is that found along the shelf off the southern coast of Australia (Wass, Conolly, and MacIntyre, 1970). There, bryozoan fragments comprise up to 85 % of the shelf sands. The greatest concentration occurs in water 43-65 m deep, with a temperature range of 11°-20° C. The temperature range that is postulated for the New Zealand Waitakian seas is slightly warmer--22°-24° C (Hornibrook, 1968). The Stony Creek bryozoa probably grew in shallow, agitated waters, 20-80 m deep. The distribution of bryozoan limestones in the Nelson province suggests the presence of a region-wide shelf or bank environment during the Oligocene.

Glasseye Mudstone deposition occurred throughout the southern half of the study area during Oligocene time. The widespread distribution of the mudstone and its interbedding relationship with the Kongahu Member form the basis of the contention that the Glasseye Mudstone is the "background" or normal basin sediment.

The Glasseye Mudstone consists of a calcareous detrital lutite with fine sandy and silty laminations. The fine grained nature of the sediment suggests that it accumulated by the slow settling out of suspension of fine particles. Sparse parallel continuous laminations are the dominant inorganic sedimentary structures. The laminations usually consist of layers of fine sand and silt and may have been current deposited.

The mudstone is bioturbate which implies oxidizing bottom conditions. The presence of pyrite, carbonate concretions (Chap. 7), and rare undisrupted laminations suggests that local reducing conditions existed below the sediment surface. <u>Planolites</u>, <u>Arthrophycus</u>, and <u>Zoophycus</u> are the dominant ichnofossils. All are fodinichnial traces; this implies that the sediment was generally palatable to burrowers and that the reducing conditions were either localized or developed later during diagenesis.

The clay content of the Glasseye Mudstone, which was probably derived largely from landmasses to the west and south of the study area (Fleming, 1975), consists mainly of montmorillonite and illite (Table 6/2). Fine grains of quartz and very minor feldspar, which was probably derived from the west, comprise the detrital sand fraction. This interpretation is based on the combined CMo transparencies (Chap. 5), which reveal that the sand fraction of the coastal mudstone samples is slightly coarser than that of the inland mudstone samples. Biological mixing introduced sand and allochem grains into the Glasseye Mudstone from the Kongahu Member. Coastal mudstone samples (from the area of greatest Kongahu Member concentration) are sandier than those from the inland areas.

The mudstone contains much finely divided terrestrial plant debris and numerous whole leaves, which are particularly abundant near the coast. The excellent state of preservation of the leaves, and the concentration of plant detritus along the coast can perhaps be taken to imply that a vegetated landmass lay somewhere to the west (of the present coastline). The allochem assemblage (Table 6/6) and the presence of Zoophycus suggest that the Glasseye Mudstone accumulated in a low energy, open oceanic environment, which was below wave base--possibly at a depth of 150-300 m.

A submarine fan paleoenvironmental model is envisioned for the Kongahu Member. The fan underwent two stages of development: (1) early formation and maturity; and (2) decline.

The early formational stage was simultaneous(?) with the uplift of the western landmass. Large blocks spalled off the rugged cliffs and formed the unstratified to crudely stratified conglomerates and breccias at Kongahu and Gentle Annie Points (Logs 4 and 7). The cutanic microtexture (Chap. 5) in the sediment near the base of the formation at Kongahu Point may be indicative of a pedogenic origin for the sediment. If this is so, then the lower Kongahu Point breccias and conglomerates may represent a reworked "soil" or rock with a soil cover. These sediments have been eroded from a western upfaulted block of the Karamea Peninsula. The lower breccias and conglomerates formed the foundation of the fan sediment pile, which subsequently prograded into the deeper, quieter environment of mud deposition.

Continuing deposition enlarged the fan, which spread eastwards. The upper portion of the fan may have consisted of a narrow wave-cut shelf on which sediments accumulated prior to redeposition into deeper waters. Many of the boulders are subangular to rounded (Chap. 5). This may be attributed to a brief residence in a high energy environment (possibly a surf zone) before redeposition. The flora and fauna assemblage (Table 6/7) and the presence of rhodolites (see above) also suggests that the upper fan was shallow and above wave-base.

Unstable sedimentary conditions were present on the fan environment and surrounding seafloor during Oligocene time. Open cast slumping of the Little Wanganui type generally occurs in areas of rapid sedimentation (Reineck and Singh, 1973). These are commonly unstable regions characterized by steep slopes and (or) tectonic activity. The slumping was probably related to the emplacement of the Kongahu Member beds, or it may have occurred when the underlying Glasseye Mudstone was liquified by sudden shocks (e.g., earthquakes) or rapid sedimentation (c.f., Bouma, 1962). Clastic dikes and water expulsion structures in the Kongahu Member (Chap. 4) imply that situations of excess pore pressure existed periodically and resulted in liquification and injection after sudden loading or seismic triggering.

Pebbly mudstones occur along the coast south of Little Wanganui. Crowell (1957) hypothesized that pebbly mudstones originated when slumping mixed coarse sediment with underlying mud. Hyne, Goldman, and Court (1973) suggested that pebbly mudstones could form when redeposited sediments underwent rapid de-watering. The pebbly mudstones in the study area are occasionally found above slump surfaces. It is highly likely that these pebbly mudstones represent a mixture generated by slumping of beds of the Kongahu Member and Glasseye Mudstone.

Channel structures developed early in the history of the Kongahu Member (Chap. 4, Figs. 4/1-4/5, and Log 5) and probably covered the surface of the submarine fan, running roughly parallel to the paleoslope. Carter and Lindqvist (1975), and Walker (1975), among others describe similar channels. The channels acted as conduits along which some Kongahu Member sediments travelled to deposition sites in deeper waters. The channels filled when downslope blockage occurred or when the shear resistance of the sediments within the channel exceeded the gravitational shear stress, because of a loss of pore water-pressure (c.f., Dott, 1963). The two channel infilling types (Types I and II, see Chap. 4) are often stratigraphically close to each other and may occur within the same channel (e.g., Figs. 4/2-4/5). The juxtaposition of widely different sediment types may be accounted for by the submarine fan model. Using this model, the Type II breccias represent sediments from a more proximal fan environment, which have "prograded" into the more distal fan environments (Type I sedimentation) during a period of temporary halt in basin subsidence.

The submarine fan model partially accounts for the wide variation in groove trends (Fig. 4/25) (c.f., Bouma, 1962). Migration of the fan lobes, spreading of the sediment on the lower fan slopes, and sediment from different fan lobes could have created the divergent pattern of groove distribution (e.g., Fig. 8/7). During the time represented by these rocks (early to mid Whaingaroan-late Duntroonian), sedimentation may have occurred on numerous small fan lobes or on larger lobes, which were covered with an intricate system of channels. Sediments moving along a branching channel system may leave widely divergent groove trends.

Decrease in grain size, thickness and frequency of beds of the Kongahu Member heralded the decline of the Kongahu Member fan in late Duntroonian time (see Log 7). A probable reduction in the relief of the study area was the cause of the demise of the fan. Unstable sedimentary

FAN MODEL AND POSSIBLE RELATIONSHIP TO GROOVE CAST TRENDS

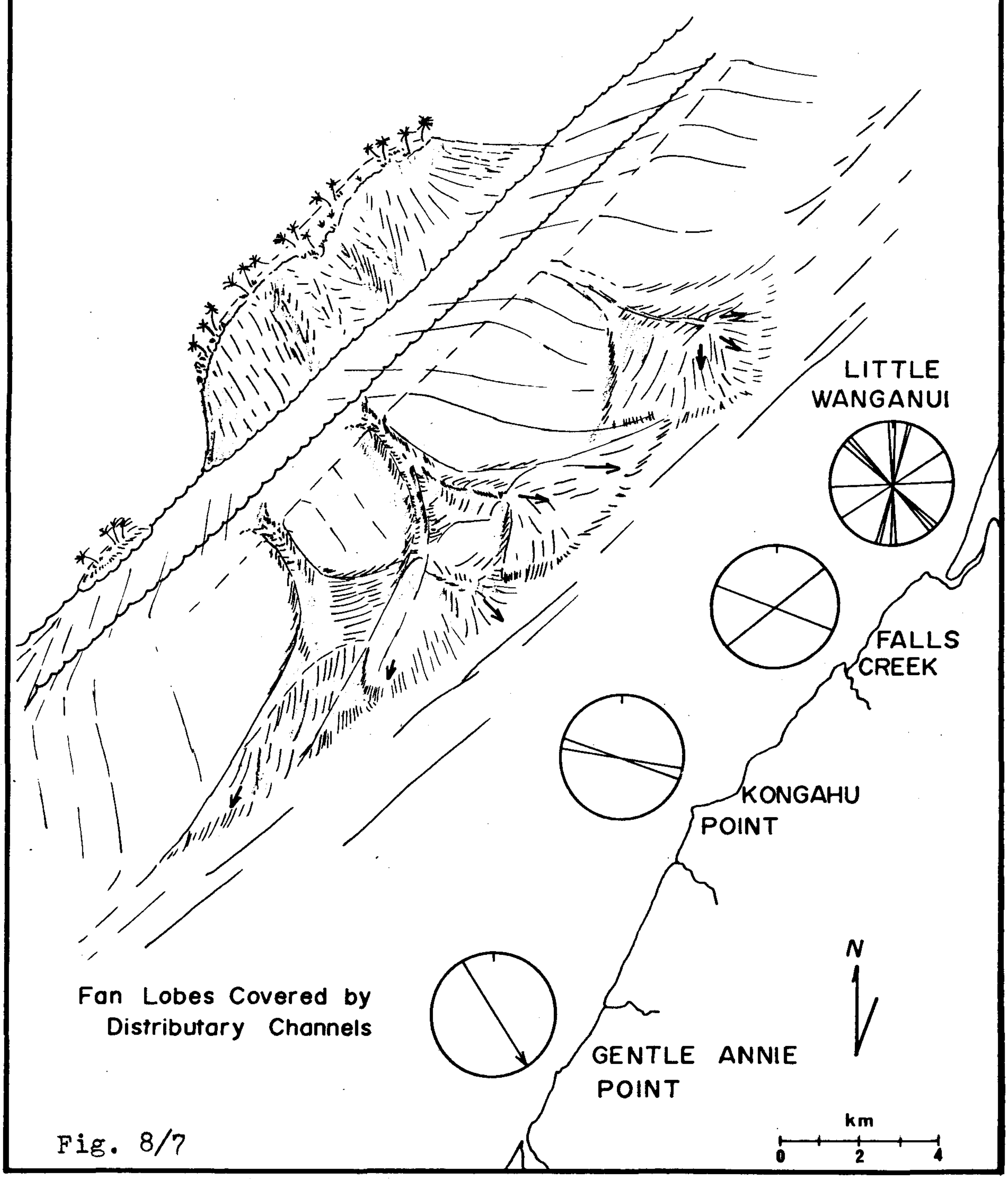


Fig. 8/7

conditions, which were evidenced by large scale slumping of Waitakian Glasseye Mudstone at Little Wanganui (Log 7), continued well after the disappearance of the Little Wanganui Fan.

Mass emplaced sediments constitute the Kongahu Member. Kongahu Member bed geometry and character (Chap. 2 and Logs 5-8) support this hypothesis. The beds of the Kongahu Member commonly have sharp erosive bases and flat, sharp tops; features which are characteristic of mass-emplaced sediments. The beds were deposited as lenses, which covered areas of widely varying extent. Lenticular beds closely resembling those of the Kongahu Member have been attributed to emplacement by debris flows (Mountjoy, Cook, Pray, and McDaniel, 1972). The Kongahu Member is very poorly sorted and often contains large clasts that are dispersed in a finer matrix. The poor sorting and irregular distribution of large clasts are characteristic of mass emplaced sediments (Johnson, 1970). The composition of the sediment also suggests a mass emplaced origin. The allochems (Table 6/7) constitute a shallow water assemblage, which contrasts with the relatively deep water assemblage of the Glasseye Mudstone (Table 6/6).

The Kongahu Member beds contain a high percentage of detrital material, including large granite clasts and intraclasts of mudstone. Concentrations of intraclasts often occur in the upper portion of the beds (Logs 5-8). The composition and color of the intraclasts corresponds with that of the Glasseye Mudstone. Apparently, the clasts represent pieces of mud, which are torn from the underlying beds by the mass emplaced deposits. Intraclasts are characteristic of transportation mechanisms, which pluck and erode at the underlying and marginal sediments. The frequent occurrence of intraclasts in the upper half of the beds suggests that the mass-transported sediment was fluid enough to allow some density(?) segregation of the particles. Many authors have documented occurrences of intraclasts in redeposited beds, for example: Mattinsson(1968) noted intraclasts near the top of conglomerate, which was emplaced by high density flows; Middleton and Hampton (1973) found intraclasts in grain-flow deposits; Carter and Lindqvist (1975) noted intraclasts in submarine channel sands.

The sedimentary structures of the Kongahu Member are representative of those which occur in mass-transported sediments. These include grading, horizontal lamination, groove casts, slümping, load casts, and clastic dikes, among others. Poorly to well developed normal grading occurs in some beds of the Kongahu Member (Chap. 4). Graded bedding has been observed in a wide range of depositional environments. Turbidity currents, debris flows, wave action on beaches, storm activity, and burrowing can create grading in marine sequences. Turbidity currents or waning normal currents may be responsible for some of the graded fine sandstones and calcarenites (c.f., samples UC 7458 M, 7463 C). The graded conglomerates (e.g., Fig. 4/14) were most likely deposited by some other mechanism(s), possibly debris flows.

Rare, diffuse planar laminae are found in some beds of the Kongahu Member near Corbyvale and View Hill Saddle (Fig. 4/12). The laminae suggest that some particle segregation took place during deposition of the beds. Horizontal laminations impart little information concerning current conditions since the structures can form in all current regimes. Carter and Lindqvist (who attributed the laminations to laminar shear during mass emplacement) (1975, Fig. 6, p. 473) depict diffuse parallel laminations, which correspond with Little Wanganui laminations.

Sets of wavy and planar laminae, which are rich in plant detritus, are often found above or associated with calcareous beds of the Kongahu Member (Fig. 4/14). The muddy laminations may represent eroded fine sediments, which were entrained by the mass transported Kongahu Member sediment as it travelled downslope (c.f., Middleton, 1967). Alternatively, the laminations may be a result of laminar shear, which occurred during emplacement of the bed (c. f., Stauffer, 1967).

Groove casts in the Kongahu Member were gouged in the cohesive mud by a rapidly moving mass of coarse debris similar to that overlying Glasseye Mudstone at Gentle Annie Point (Chap. 4). The *in situ* tools at Gentle Annie Point provide a definite sense of direction to the groove cast trends; the tools moved from NW to SE.

Slumping is a common feature in the Kongahu Member and implies unstable sedimentary conditions on the fan.

Slumping may have triggered mass emplacement of the turbidites (c.f., Morgenstern, 1967), debris flows and slump packets that characterize the Kongahu Member. Slump scars could have provided the initial locus for channel development.

The presence of secondary sedimentary structures, including load casts, slump balls, and flame structures (Chap. 4), suggests that density and (or) cohesion differences existed between the soft to stiff plastic mud (Glasseye Mudstone) and the overlying sediments.

The types of channel infilling reflect the mechanisms of deposition and possibly the degree of efficiency with which basin subsidence assimilated the incoming sediments. Type II infillings (Chap. 4), consisting of granite breccias and breccia/conglomerate sands, show some stratification and rare, very crude normal grading. The Type II infilling resembles the mass emplaced Lithofacies B of Carter and Lindqvist (1975). The Type I infillings consist of thin- to thick-bedded sands, which sometimes contain scattered granite clasts. This type of infill commonly shows stratification, normal grading, and rare, wispy, horizontal laminations of dark mud. The Type I infilling is similar to Carter and Lindqvist's (1975) Lithofacies C and D, which they argued were emplaced by a variety of mass-flow mechanisms.

The differences in grain size, sorting, and internal organization between infilling Types I and II (Chap. 4) suggest that at least two different modes of transportation are represented. The inferred, Type II transporting medium was relatively more powerful than that of the Type I, as evidenced by the extreme size of the granite clasts. The medium which emplaced the Type II sediments was probably very viscous and allowed little opportunity for particle sorting.

Thin, very muddy and fine sandy beds of the Kongahu Member (c.f., samples UC 7455 J, 7458 M, 7463 B) which lack large granite clasts, erosively overlie Glasseye Mudstone and are probably of mass-emplaced origin. These beds of the Kongahu Member are appreciably coarser than the "background sediment" and contain abundant pelagic foraminifera and sponge spicules and sparse fragments of red algae and bryozoa. The allochem assemblage, which greatly resembles that of the Glasseye Mudstone (Table 6/6), suggests that the redeposited sediment originally accumulated in or near the mudstone environment. Turbidity currents may have emplaced the muddy Kongahu Member sediments as they contain some crude grading and faint parallel laminations. Debris flows or slumping may have triggered the turbidity currents.

The Kongahu Member sediments have many ancient analogues. The closest, in space as well as in sedimentary conditions, is the Torea Breccia of northwestern Buller (Laird and Hope, 1968). The Oligocene Sealers Bay submarine fan complex, at Chalky Island, southwest Fiordland (Carter and Lindqvist, 1975), is similar in many ways to the Little Wanganui situation. The Late Mesozoic conglomeratic flysch deposits in Oregon

(Aalto and Dott, 1970) also bear a striking resemblance to the Kongahu Member beds. An appropriate modern analogue for the Kongahu Member-Glasseye Mudstone sediment assemblage may be found in Baja, California (on the eastern side), where gravels are accumulating at the edge of marine deeps (Aalto and Dott, 1970).

Three sediment types can be distinguished within the poorly exposed Oparara Member. In the Karamea region the sediment is a fine grained, well washed echinoderm bryozoan biosparite. The allochems are intensively bored and the borings are filled with glauconite. The small grain size, the intensive boring, and the abundance of glauconite suggest slow sedimentation on a current swept shallow shelf.

At Limestone Creek, a muddy very fine sandy biomicrite, containing numerous pelagic foraminifera, crops out above the Stony Creek Limestone (Chap. 3, Log 4). The sediment resembles the Glasseye Mudstone but is slightly darker and contains numerous patches of chalcedony. Pelagic foraminifera and echinoderm fragments are present. The fine grain size of the sediment suggests that it was deposited in a low energy environment. The numerous pelagic foraminifera and the scarcity of bryozoan fragments implies that the sediment accumulated in an area that was slightly deeper than the Oparara Member environments to the north and south. Further sampling is necessary to determine if this sediment is contiguous with the Glasseye Mudstone.

A slightly muddy foraminiferal bryozoan biosparite which contains numerous _Amphistegina_ represents the Oparara Member at Glasseye Creek. The intensively bored allochems and the presence of glauconite suggest a depositional environment similar to that found in the Karamea region. Near Happy Valley Saddle the limestone is pebbly. The detrital fraction is well sorted and bimodal. Well rounded very fine pebbles contrast with angular medium to very coarse sand. The bimodal roundness probably reflects the natural tendency for coarser grains to round before finer grains. The bimodal size distribution may be the result of reworking of polymodal Kongahu Member sediments during the formation of the late Oligocene regional unconformity. The high degree of sorting, lack of mud, and coarse detrital grain size indicates a high energy depositional environment.

CHAPTER 9

SUMMARY

This report details the broad sedimentological characteristics of the Oligocene and lowest Miocene sediments in the southwest corner of Nelson province. The lithostratigraphic classification of Nathan (1973) was extended to the area, with modifications. The classification (Chap. 2 and below) includes two new formations and five new members.

Group	Formation	Member
undifferentiated Blue Bottom Group		
Nile Group	Karamea Limestone (new)	Oparara Member (new)
		Stony Creek Limestone (new)
	unconformity	
	Little Wanganui Formation (new)	Kohaihai Limestone (new)
		Glasseye Mudstone (new)
		Kongahu Member (new)
undifferentiated Mawheranui Group		
Rapahoe Group	Kaiata Formation	Kaiata Mudstone

Local normal faulting along the Paparoa Tectonic Zone (Laird, 1968) during the early and middle Tertiary created an archipelago of small landmasses accompanied by NNE-trending sedimentary troughs. The Little Wanganui area basin with its associated western landmass is the most northerly documented extension of the Paparoa Tectonic Zone. The basin was active from early Whaingaroan to Waitakian time and marked the final phase of the tensional stress regime along the Paparoa Tectonic Zone. Troughs similar to the one at Little Wanganui are located near Greymouth and Granity.

During late Eocene time the low-lying Karamea Peninsula covered all but the extreme southwest corner of the study area, in which the shallow(?) marine Kaiata Mudstone accumulated. The coal-bearing Mawheranui Group accumulated along the margins of the peninsula and was conformably overlain in the Little Wanganui area by the Kaiata Mudstone.

A granitic landmass or series of islands emerged to the west of the Little Wanganui area in early Whaingaroan time. A western landmass is indicated by the distribution of the Kongahu Member, the groove cast trend data, and the CMo and DAM diagrams (Chap. 8). The landmass, which initially had a rugged relief, was the source of the Kongahu Member. Sediments of the Kongahu Member initially interbedded with the Kaiata Mudstone and slightly later, the Glasseye Mudstone--a deeper water lithology, which accumulated in the area as the regional Eocene-Oligocene transgression progressed.

The Kongahu Member consists entirely of mass-transported sediments that accumulated in the rapidly subsiding Little Wanganui trough. The bed form, sedimentary structures, and displaced shallow water fossil assemblage are consistent with the mass-transportation hypothesis. The Kongahu Member may have initially accumulated at the foot of granite cliffs. The earliest conglomerates and breccias at Kongahu Point possibly represent reworked soils or rocks with a soil cover (Chaps. 5 and 8). Gradually a fan developed and prograded into deeper, quieter depositional environments to the east.

The sediments of the Kongahu Member may have accumulated temporarily on a narrow wave-cut shelf prior to redeposition into deeper waters. In the surf zone, large boulders underwent minor rounding. In slightly deeper waters red algae encrusted pebbles and formed rhodolites. Covering the shelf and upper slopes of the fan were lush growths of bryozoa. Red algae encrusted some of the loose detritus, while Amphistegina and other benthonic foraminifera crawled among the bryozoan-encrusted grasses. Echinoderms grazed in the sandy patches and burrowed below. Earthquake-triggered slumps and debris flows (c.f., Johnson, 1970) may have ploughed through the soft lower slope sediments forming channels, along which other sediments were subsequently transported. Sediment moved down the channels by a variety of mass-transport mechanisms. Filling of the channels commenced when the shear resistance of the sediment within the channel exceeded the shear stress of gravity. Downslope blockage of the channels may also have caused the channels to fill. Not all coarse sediment followed the channels during transportation. Some, possibly those evolving from slumps, spread over small sections of the fan. The sediment contained clasts, which gouged linear grooves into the underlying mud as the mass progressed downslope. Internal shearing of the mass-transported sediment or entrainment and settling of fine sediment by the moving debris created diffuse wavy and planar laminae in the beds of the Kongahu Member. Slumping or other mass-transport mechanisms may have generated small turbidity currents, which carried fine sand, sponge spicules, and foraminifera tests into deeper waters to be deposited as thin graded beds. They accumulated on the outer fan, an area where the water was cold and relatively deep (perhaps 150-300 m). In the outer fan environment siliceous sponge colonies, echinoderms, and possibly the conical fecal mounds of burrowers may have been the only signs of life.

The Torea Breccia (Laird and Hope ,1968) is the closest ancient analogue to the Kongahu Member-Glasseye Mudstone sedimentary situation. It was also deposited within the Paparoa Tectonic Zone. Coastal sedimentation along Baja California provides an appropriate modern analogue for the Kongahu Member (Chap. 8, Aalto and Dott, 1970).

In the Karamea-Kohaihai Bluff area, the coaly Mawheranui Group was overlain (in early Whaingaroan time) by the marginal marine sediments (Kohaihai Limestone). Continuing transgression throughout Whaingaroan time brought about deeper, more open marine conditions.

By the end of Whaingaroan time two distinct sedimentary provinces were well established. The northern sedimentary province, which occupied the northern half of the study area, consisted of a shallow shelf on which well washed carbonate sands (Kohaihai Limestone) accumulated. A rapidly subsiding trough, in which the Glasseye Mudstone and Kongahu Member accumulated, occupied the southern half of the study area. These sedimentary provinces persisted until early Miocene times.

Sedimentation continued without apparent interruption in the southern sedimentary province throughout Duntroonian time. In the Karamea area, sedimentation slowed or ceased in late Duntroonian-early Waitakian time during a period of local uplift, which created a minor unconformity (Chap. 3, Fig. 8/3). This minor uplift stripped much of the sediment from the platform but apparently did not affect the Little Wanganui basin.

A thick bryozoan limestone (Stony Creek Limestone) marks the renewal of Waitakian sedimentation in the Karamea area. The Stony Creek Limestone is a shallow marine sediment which contains abundant bryozoa similar to the type presently living on the Great Bahama Bank. The depth of accumulation was probably 20-80 m.

In the Little Wanganui area, influxes of the Kongahu Member became less frequent in Duntroonian and ceased by early Waitakian time. A reduction in the relief of the western source area, perhaps to base level, caused the cessation of Kongahu Member deposition.

Glasseye Mudstone deposition continued until the late Landon-Pareora regional uplift, which affected northern Buller and the southern sedimentary trough area. The uplift removed some of the mudstone and created the unconformity that is present at Glasseye Creek and at Happy Valley Saddle (Logs 7 and 9). The unconformity did not extend to the Karamea area.

Shallow marine shelf conditions were present throughout the study area from the beginning of the Miocene when Oparara Member deposition commenced. The Oparara Member is generally a shallow shelf limestone. However, the exposure at Limestone Creek (Log 4) may be of a slightly deeper-water facies, deposited in a remnant of the Glasseye Mudstone basin.

Blue Bottom siltstone and sandstone conformably overlie the Oparara Member throughout the study area and probably represents a low energy, shallow shelf environment. These sedimentary conditions prevailed in the study area throughout Miocene time.

A change in the stress regime along the Paparoa Tectonic Zone in the Early Miocene resulted in the development of late Tertiary and Quaternary monoclines, reverse faults, and overfolds (e.g., the overturned beds at Gentle Annie Point). Extensive faulting took place during the Kaikoura Orogeny. The present cliffed coastline topography may be a result of movement along the Kongahu Fault during the Kaikoura Orogeny.

The Nile Group sediments contain only low temperature and pressure diagenetic features, which imply that the sediment was not deeply buried.

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APPENDIX I

Over 1200 points were counted on nine samples to test the accuracy of the estimation of component percentages in thin section by visual means. The visual estimate of total detrital content commonly exceeded the point count percentage by an average of 2.3 %; the visual estimates ranged from a relative underestimate of 5 % to an overestimate of 8 %. Overestimations of the microcline content and underestimations of the rock fragment content were common in the visual method. The allochem content was slightly underestimated (0.5 %) by the visual method. The visual estimations ranged from a relative underestimation of 6 % to a relative overestimation of 5 %. The percentages of echinoderms and foraminiferal fragments were generally underestimated relative to the point count method; while, bryozoan and red algal content was generally overestimated. Visual estimations of the mud content averaged about 0.5 % lower than the point count figure (see Figs. I/1-3).

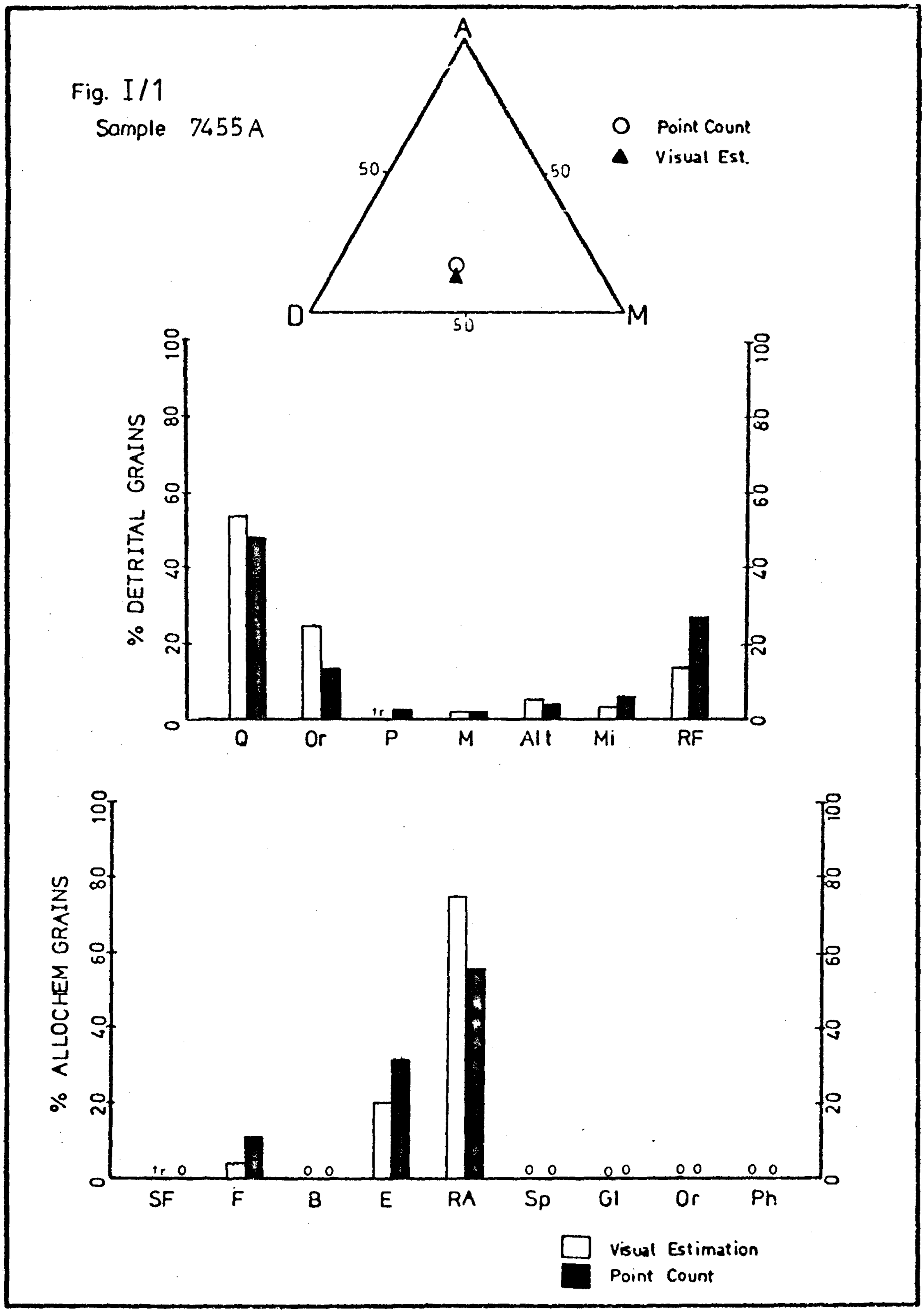


Fig. I/1
Sample 7455 A
A
D
M
50
50
50
Point Count
Visual Est.
% DETRITAL GRAINS
0
20
40
60
80
100
Q
Or
P
M
Alt
Mi
RF
tr
% ALLOCHEM GRAINS
SF
F
B
E
RA
Sp
Gl
Or
Ph
tr
Visual Estimation
Point Count

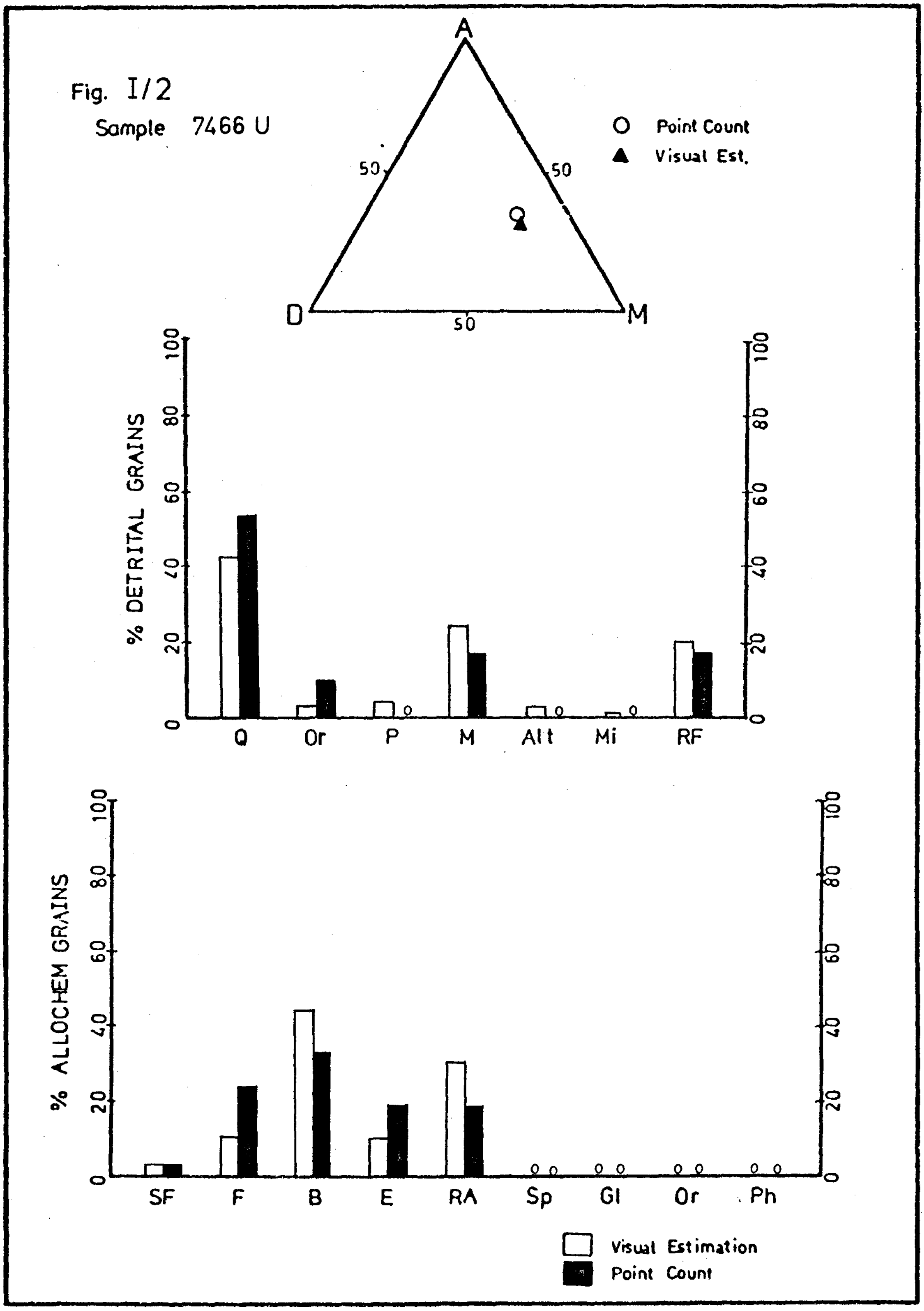


Fig. I/2
Sample 7466 U
A
D
M
50
50
50
Point Count
Visual Est.
% DETRITAL GRAINS
0
20
40
60
80
100
Q
Or
P
M
Alt
Mi
RF
% ALLOCHEM GRAINS
SF
F
B
E
RA
Sp
Gl
Or
Ph
Visual Estimation
Point Count

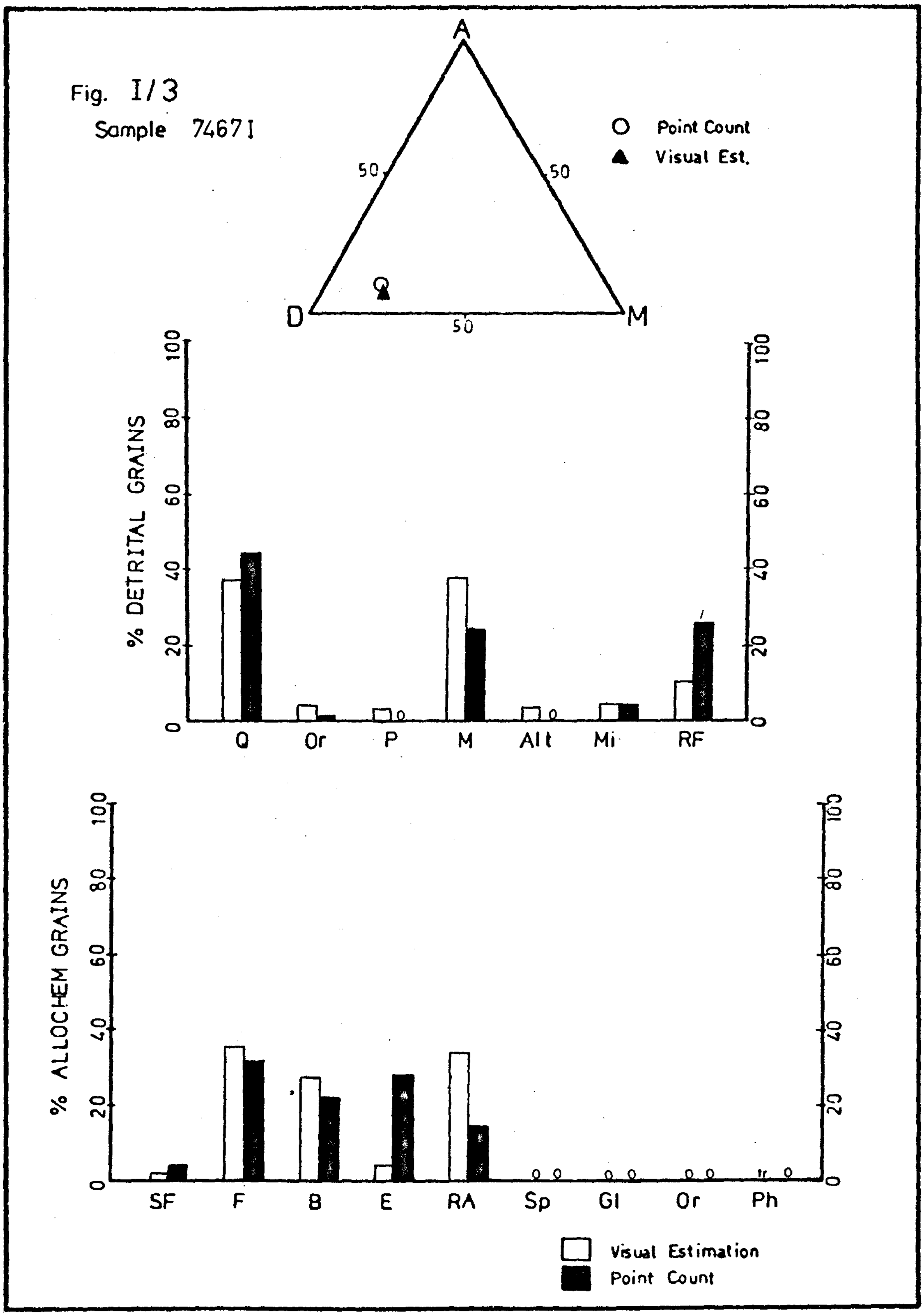


Fig. I/3
Sample 7467I
A
D
M
50
50
50
Point Count
Visual Est.
% DETRITAL GRAINS
0
20
40
60
80
100
Q
Or
P
M
Alt
Mi
RF
% ALLOCHEM GRAINS
SF
F
B
E
RA
Sp
Gl
Or
Ph
tr
Visual Estimation
Point Count

APPENDIX II

FORAMINIFERA LISTS FOR THE KOHAIHAI LIMESTONE, GLASSEYE MUDSTONE, AND OPARARA MEMBER

KOHAIHAI LIMESTONE MICROFOSSIL LIST

References: N. Z. Fossil Record Forms

Sheet Fossil No.	Field No.	Sample No.
S12/501	656	F 10281
S12/502	657	F 10282

Amphistegina

Anomalina subnomionoides

Anomalinoides subnomionoides

Bolivina anastomosa

Cassidulina subglobosa

Cibicides molestus

Discorbis scopos

D. "stellabasis"

Elphidium advenum

E. cf. *"striatissima"*

Gyroidina allani

Lamarckina

Nonion pompiloides

Notorotalia cf. *crespinae*

N. spinosa

N. aff. *tenuissima*

KOHAIHAI LIMESTONE MICROFOSSIL LIST (CONT.)

Kohaihai Bluff: S12/521 551; Sample UC 7451 A; Exact position shown on Log 1 (back pocket)

Anomalinoides fasciatus

Chiloguembelina cubensis

Discopulvinulina turgida

Globigerina euapertura

Guembelitria stavensis

Guttulina fissurata

G. yabei

Gyroidinoides allani

Lagena anomala

Notorotalia spinosa

Sphaeroidina bulloides

Trifarina bradyi

Stony Creek: S12/472 561; Sample UC 7452 B, Exact position shown on Log 2 (back pocket)

Anomalinoides fasciatus

Discopulvinulina turgida

Globigerina bulloides

Globorotalia cf. ciperoensis angustimplicata

G. munda

G. nana nana

Guttulina fissurata

G. otiakensis

Notorotalia spinosa

N. stachei

Identifications by S. W. Duff

GLASSEYE MUDSTONE MICROFOSSIL LIST

References: N. Z. Fossil Record Forms

Sheet Fossil No.	Field No.	Sample No.
S17/500	834	F 10397
S18/500	661	F 10283
S18/501	662	F 10284
S18/502	663	F 10285
S18/503	664	F 10286
S18/504	665	F 66281
S18/505	666	F 10287
S18/512	673	F 10290
S18/543	1094	F 10562
S18/544	1095	F 10563
S18/549	1232	F 10666
S18/550	1233	F 10667
S18/551	1234	F 10668
S18/552	1235	F 10669
S18/553	1236	F 10670
S18/554	1237	F 10671
S18/600	1406	F 10753

Alabamina

Amphistegina

Anomalina aotea

Anomalinoides deceptrix

A. fasciatus

A. orbiculus

A. pinguiglabra

GLASSEYE MUDSTONE MICROFOSSIL LIST (CONT.)

A. subnonionoides

Asterigina

Bolivina anastomosa

B. beyrichi

Bueningia creeki

Bulimina pupula

Buliminella pupula

Buliminoides williamsoniana

Calcarina mackayi

Cancris proamplus

Cassidulina subglobosa

Cassidulinoides orientalis

Cerobertina

Chiloguembelina

Chilostomella

Cibicides lornensis

C. robertsonianus

C. thiara

Cribrotalia longuoodensis

Darbyella

Ditrupa

Dorothia minima

Dyocibicides

Ellipsoglandulina subconica

Elphidium advenum

E. striatissima

Eponoides concentricus

Gaudryina crespinae

GLASSEYE MUDSTONE MICROFOSSIL LIST (CONT.)

Globigerina angipora

G. bulloides

G. euapertura

Globoquadrina dehiscens

Guttulina communis

G. regina

G. sequenzana

Gyroidinoides allani

Haeuslerella hectori

H. pukeuriensis

H. textilariformis

Karreriella novozealandica

Legenoglandulina

Legenondosaria hirsuta

Martinottiella communis

Nodosaria longiscata

Nonion laevimaoricum

N. maoricum

N. pompilioides

Notorotalia argentea

N. proargentea

N. spinosa

N. stachei

N. waitemata

Palmula

Parrella

Planorbulinella

GLASSEYE MUDSTONE MICROFOSSIL LIST (CONT.)

Planularia

Planulina eatilla

Plectofrondicularia awamoana

P. parri

P. proparri

P. whaingaroica

Pleurostomellidae

Polymorphina cf. chattonensis

Pseudoglandulina erecka

Pseudononion

Reophax

Rotaliatina

Sigmomorphina aff. pernula

Siphogenerina aff. striatissima

Siphonia

Sphaeroidina bulloides

Spiroloculina

Spiroplectammina aff. carinata

Technitella

Textularia zeaggluta

Trifarina planangula

Trochaminoides

Trochammina proteus

Uvigerina maynei

U. picki

Virgulina

Vulvulina granulosa

GLASSEYE MUDSTONE MICROFOSSIL LIST (CONT.)

Little Wanganui River, South Bank: near S18/507167; Sample UC 7467 Q; Exact position shown on Log 7 (back pocket)

Bolivinopsis cubensis
Dyocibicides sp.
Globigerina euapertura

Identifications by S. W. Duff

OPARARA MEMBER MICROFOSSIL LIST

Stony Creek: S12/474559; Sample UC 7452 H; Exact location shown on Log 2 (back pocket)

Euuvigerina miozea
Notorotalia spinosa

Identifications by S. W. Duff

APPENDIX III

VERTEBRATE FOSSILS

Ewan Fordyce (Ph.D. candidate, U. of C.) identified some cetacean remains, which were recovered from a loose block of Glasseye Mudstone south of Little Wanganui Head at S18/498158. The bones are identified as follows:

(1) eroded vertebrae with transverse (?) processes preserved

(2) a fragment of rib (?)

(3) two large, curved bones, (N. Z. Fossil Record File: Sample No. L28/f 2) (Fig. III/1)

> Recently, I placed fragments of the curved bones in dilute acetic acid and removed some of the matrix from them. It became apparent that, parallel with the long axis of each bone, there is a long suture. In cross section, this suture is concave with respect to the outside of each bone. Furthermore, on the upper (exposed, or dorsal ?) surface of the bones there are grooves which look like blood vessel foramena.
> (E. Fordyce, pers. comm., April 13, 1976).

Fordyce suggested that the bone may be the rostrum of a mysticete cetacean, similar to Mauicetus (Mid Oligocene, New Zealand). If this specimen belongs to a mysticete whale it is the first Lower Oligocene representative of the suborder Mysticeti and the oldest known mysticete by at least 5 million years.

A rock containing fragments of a cetacean skull was found on the beach near Falls Creek at S18/493153. The

Figure III/1 Cetacean bones in (L28/f2), possibly the rostrum of a mysticete whale, in Glasseye Mudstone, Little Wanganui Head. Scale is in centimeters.

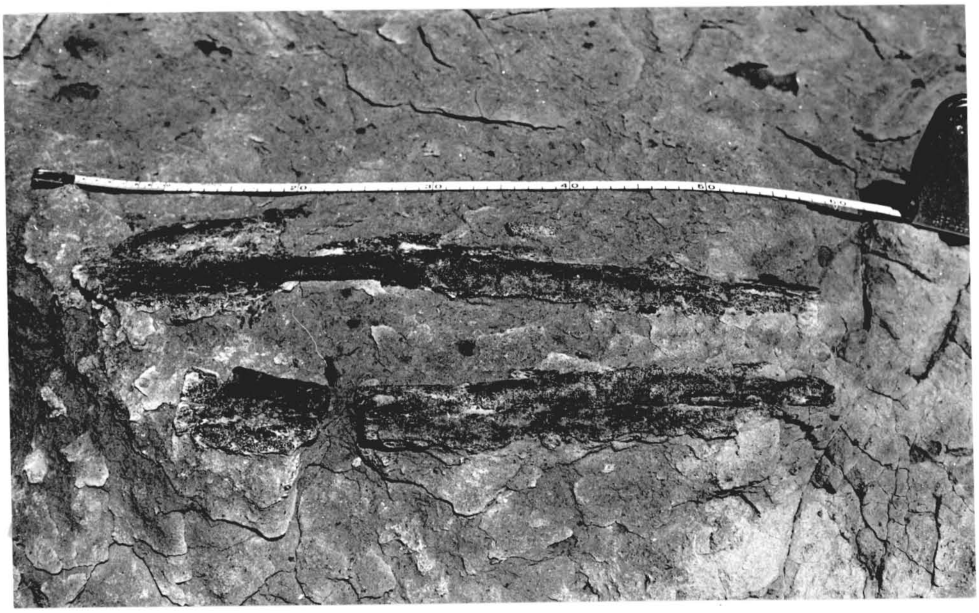
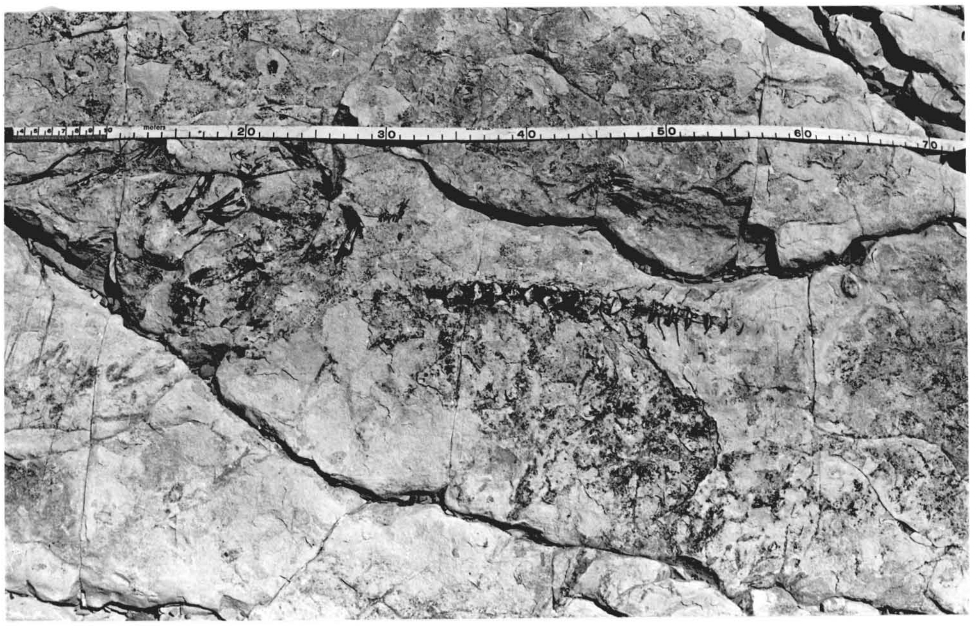


Figure III/2 Skeleton of fish in Glasseye Mudstone from mouth of Falls Creek.



specimen (L28/f 3) has not been identified yet, but it represents one of the few remains of this age (Lower Oligocene) found in the world.

A skeleton of a fish (Fig. III/2) was recovered from Lower Whaingaroan Glasseye Mudstone at the mouth of Falls Creek. Restoration of the skeleton is underway at the Dept. of Geology, University of Canterbury, where the specimen will be housed.

APPENDIX IV

HELICAL INCLUSIONS IN MUSCOVITE

Interesting corkscrew-shaped inclusions were noted in some muscovite flakes, which were contained in the Kongahu Member and in one sample of the Glasseye Mudstone (see below). The isotropic inclusions spiral counterclockwise around an axis that is roughly parallel to the cleavage of the mica flake (Figs. IV/1 and 2). The maximum length of the inclusions is about 54 .

The inclusions occur in the following samples:

Kongahu Member	7455 A, G
	7457 A, B
	7458 K, M
	7461 F, G
	7467 B, I, P
Glasseye Mudstone	7467 F

A number of possible origins for the inclusions are presented.

(1) The peculiar habit seems likely to be of mineral origin. The isotropic nature of the inclusions could be a result of their extremely small size.

(2) The structures are voids or liquid inclusions. The low refractive index and isotropism is in keeping with a liquid inclusion origin. The structures may represent remnants of immiscible liquid that was present during the crystallization of the muscovite flakes.

Figure IV/1 Helical inclusions in muscovite flake (sample UC 7467 P). Plane polarized light; field of view equals .175 mm.

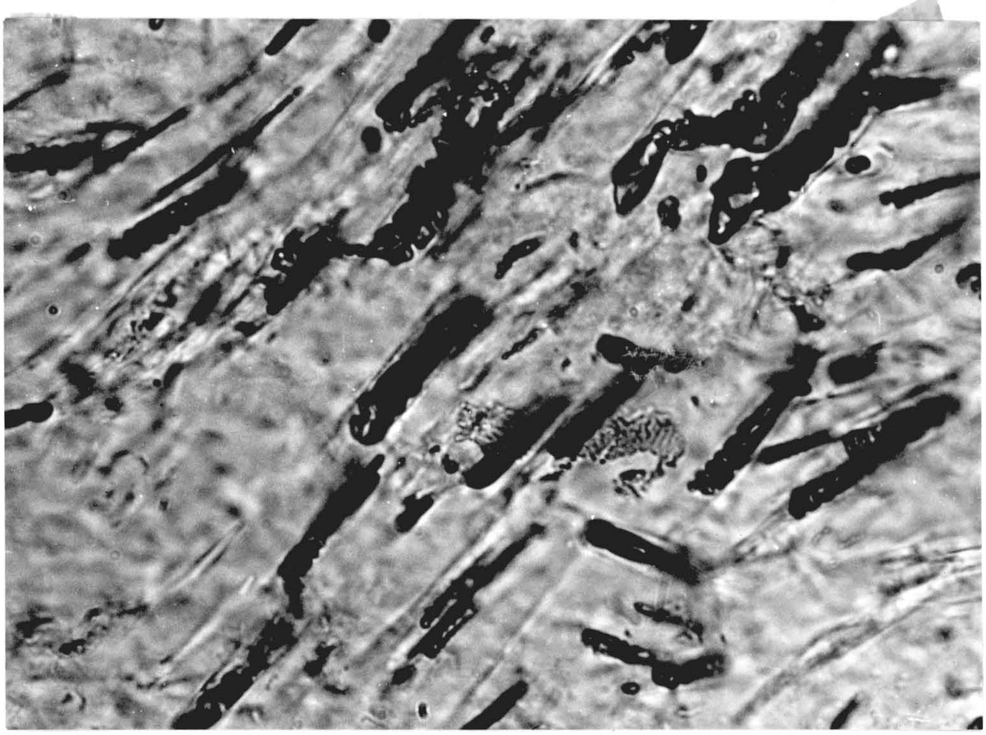
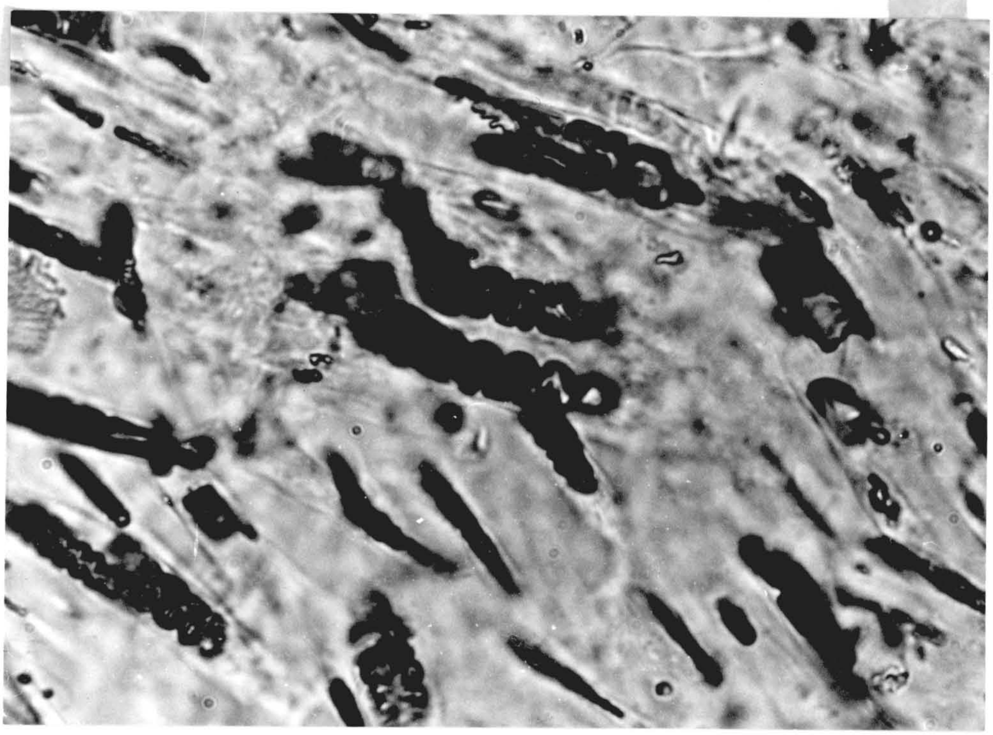


Figure IV/2 Enlarged view of above helical inclusions. Field of view equals .14 mm.



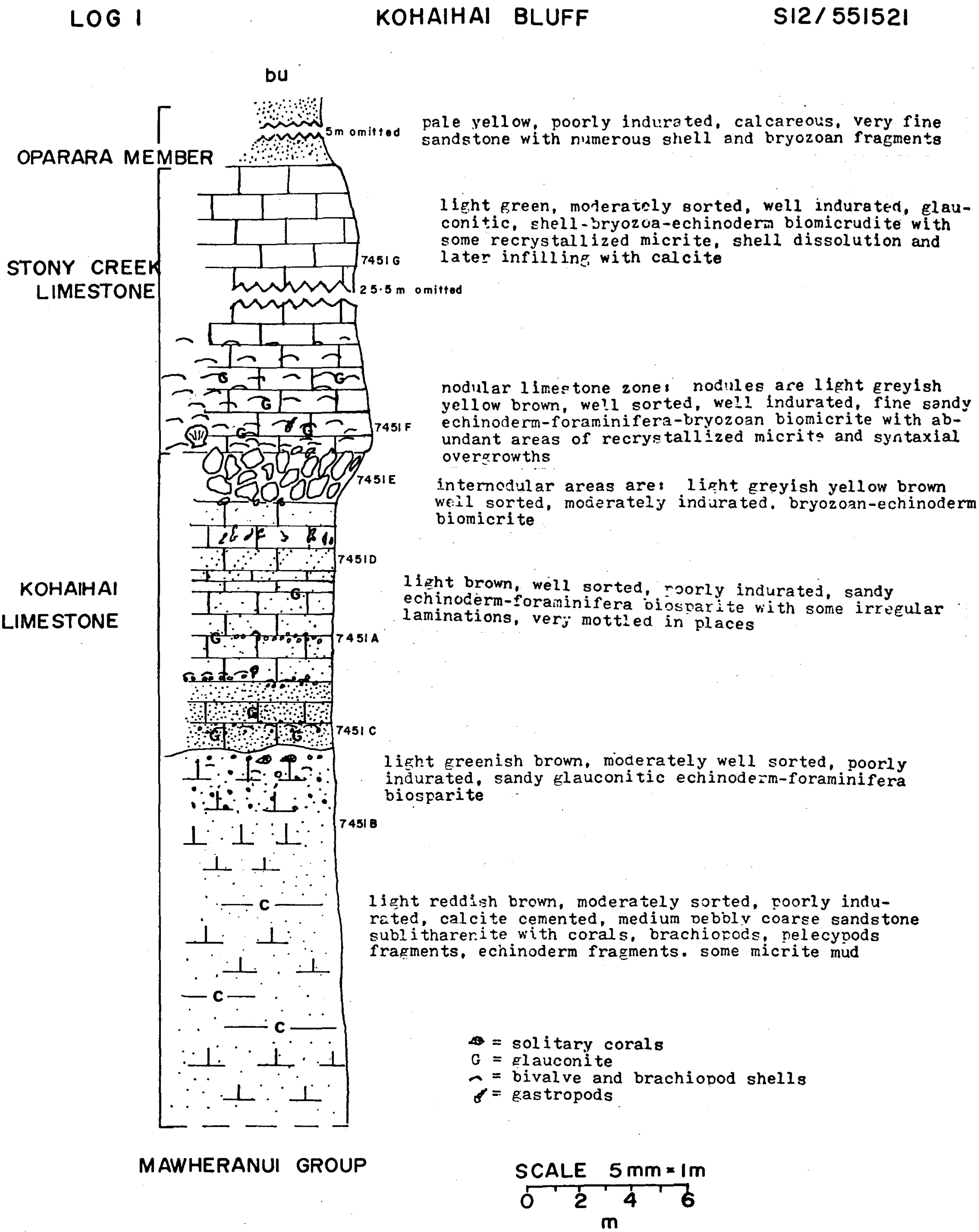
(3) The inclusions are artefacts resulting from the plastic impregnation procedure used in the production of the thin sections. Examination of unimpregnated samples is necessary to test this hypothesis.

(4) The inclusions are the result of endolithic boring organisms. This alternative seems unlikely because: no similar structure occurs in any other substrate; the structures are deeply embedded within the muscovite flakes and lack apparent access routes to the exterior of the flake.

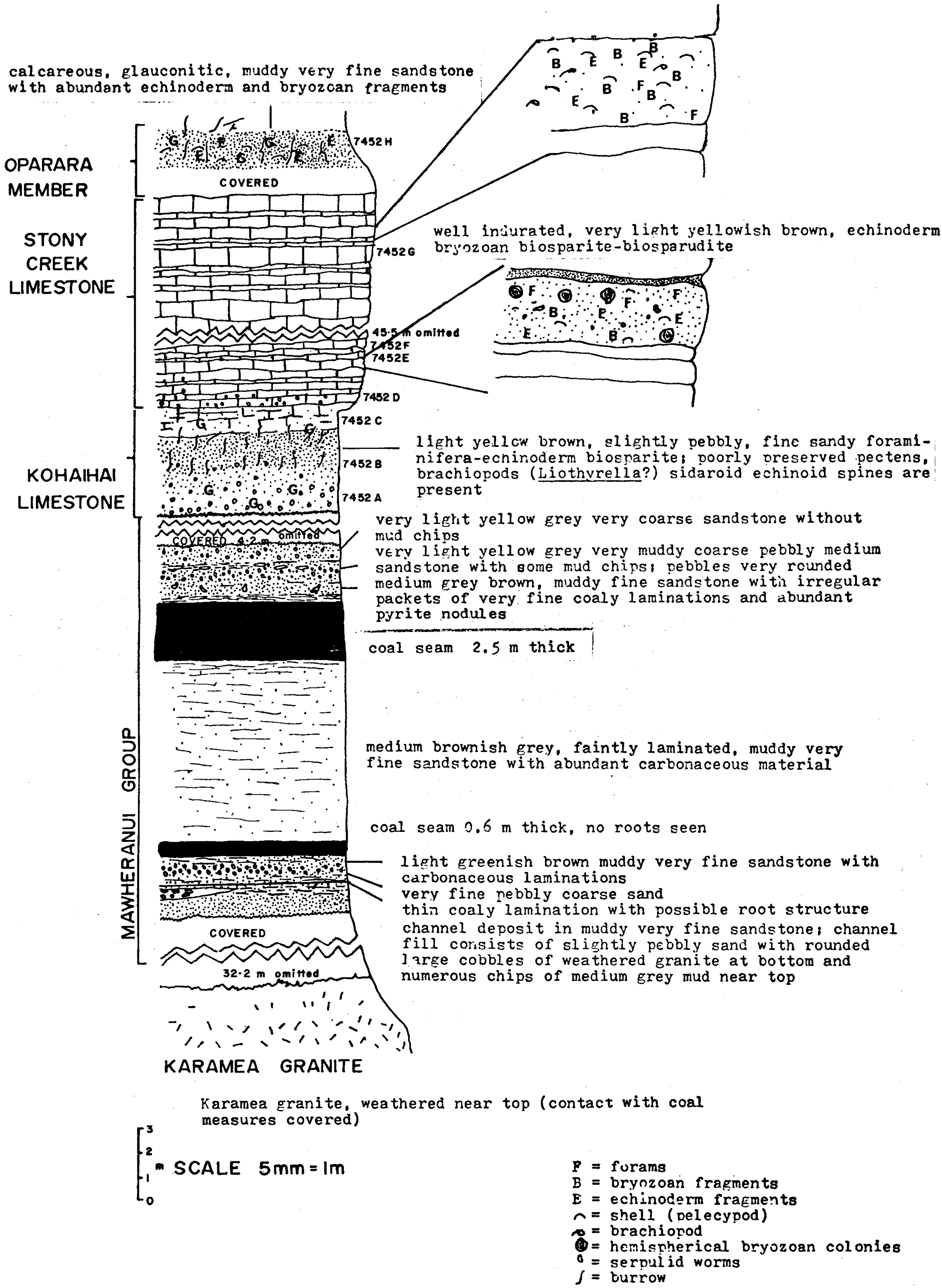
APPENDIX V

SAMPLE LOCATIONS

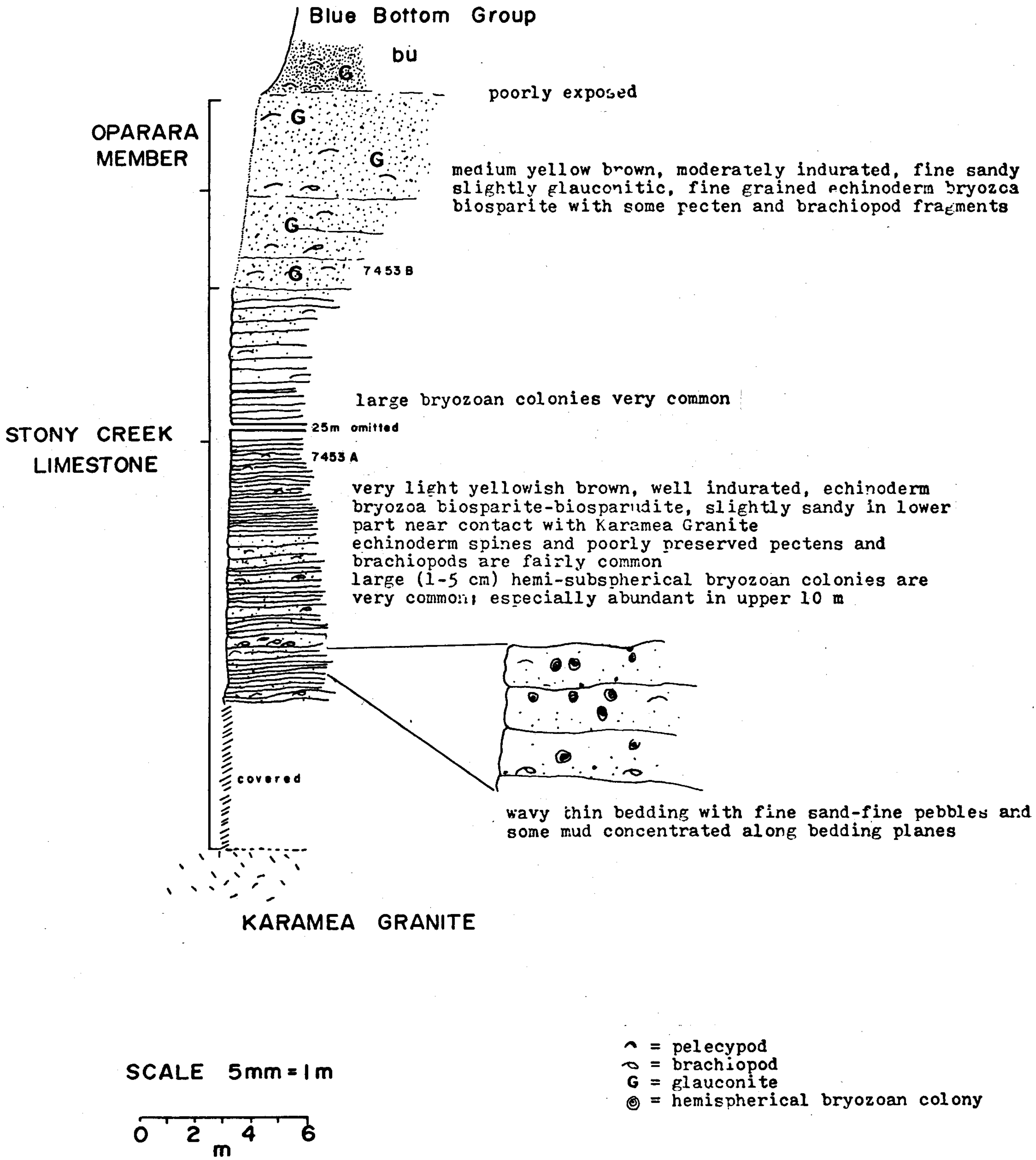
Sample Number		Locations
7451	A-G	Kohaihai Bluff (Log 1) S12/551521
7452	A-G	Stony Creek (Log 2) S12/562472
7453	A,B	Oparara River Quarry (Log 3) S12/593378
7454	A-C	Limestone Creek (Log 4) S18/658218
7455	A-M	Gentle Annie Point (Log 8) S18/409029
7456	A,B	Mouth of 3 Mile Creek S18/425047
7457	A-C	Kongahu Point (Log 5) S18/445101 to S18/465117
7458	A-O	Falls Creek (Log 6) S18/485141
7459	A-F	Glasseye Creek (Log 7) S18/513161 to S18/528098
7460		Confluence of Q and Glasseye Creeks S18/522132
7461	A-O	View Hill Saddle (Log 10) S18/476014
7462		Highway 67 immediately north of Corby-vale S18/523068 to S18/531077
7463	A-C	Highway 67, near Glasseye Creek S18/535080
7464	A-C	Highway 67, Happy Valley Saddle S18/543088
7465	A-Z	Little Wanganui Head
7466	A-Z	(Log 7)
7467	A-V	S18/495155 to
7468	A-C	S18/514162


LOG I
KOHAIHAI BLUFF
S12/551521
bu
OPARARA MEMBER
5m omitted
pale yellow, poorly indurated, calcareous, very fine sandstone with numerous shell and bryozoan fragments
STONY CREEK LIMESTONE
light green, moderately sorted, well indurated, glauconitic, shell-bryozoa-echinoderm biomicrudite with some recrystallized micrite, shell dissolution and later infilling with calcite
7451 G
25·5 m omitted
nodular limestone zone: nodules are light greyish yellow brown, well sorted, well indurated, fine sandy echinoderm-foraminifera-bryozoan biomicrite with abundant areas of recrystallized micrite and syntaxial overgrowths
7451 F
7451 E
internodular areas are: light greyish yellow brown well sorted, moderately indurated, bryozoan-echinoderm biomicrite
7451 D
KOHAIHAI LIMESTONE
light brown, well sorted, poorly indurated, sandy echinoderm-foraminifera biosparite with some irregular laminations, very mottled in places
7451 A
7451 C
light greenish brown, moderately well sorted, poorly indurated, sandy glauconitic echinoderm-foraminifera biosparite
7451 B
light reddish brown, moderately sorted, poorly indurated, calcite cemented, medium pebbly coarse sandstone sublitharenite with corals, brachiopods, pelecypods fragments, echinoderm fragments. some micrite mud
= solitary corals
G = glauconite
= bivalve and brachiopod shells
= gastropods
MAWHERANUI GROUP
SCALE 5mm = 1m
0 2 4 6
m

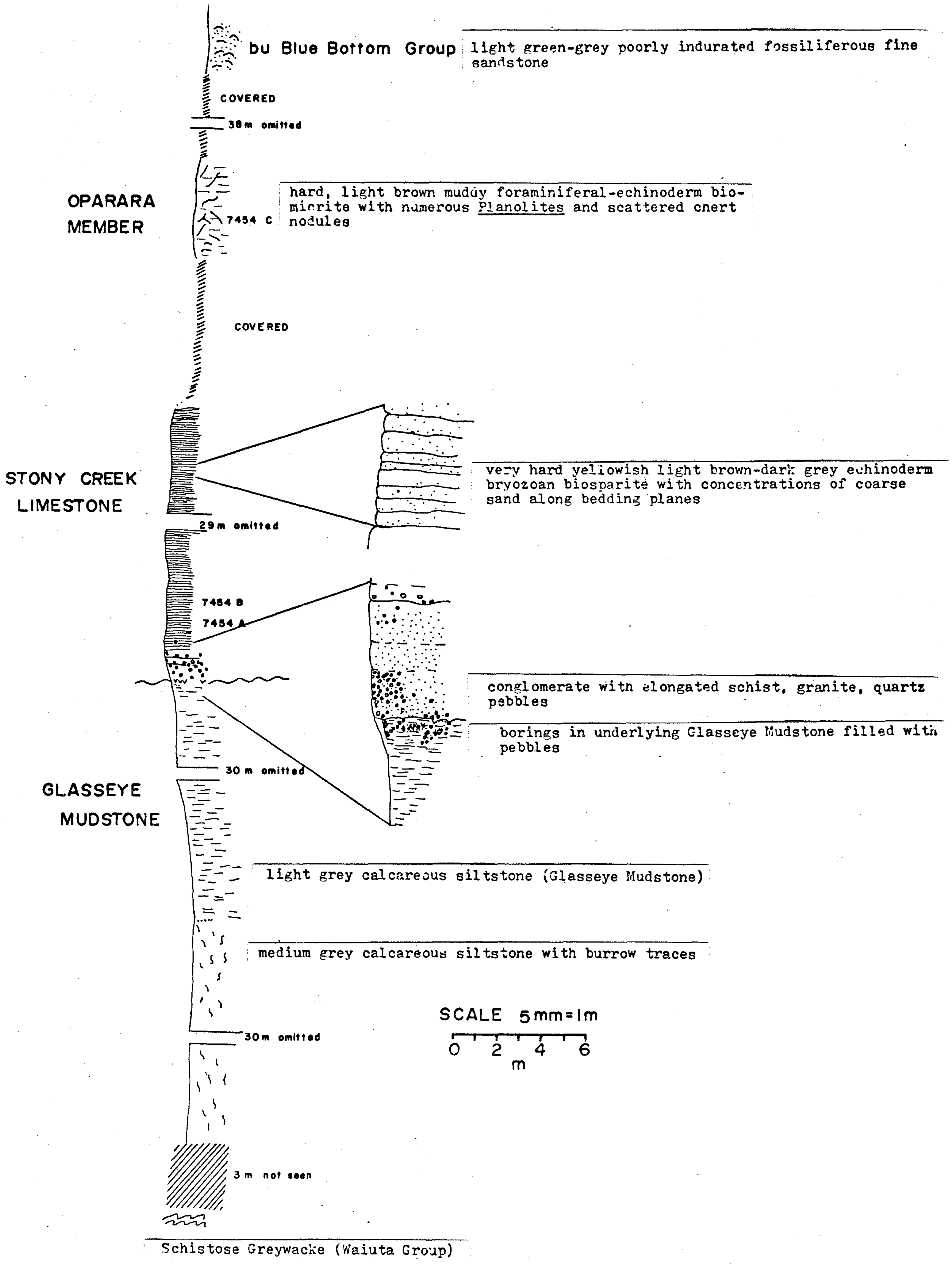
LOG 2 STONY CREEK S12/562472



LOG 3 OPARARA RIVER LIME QUARRY S12/593377

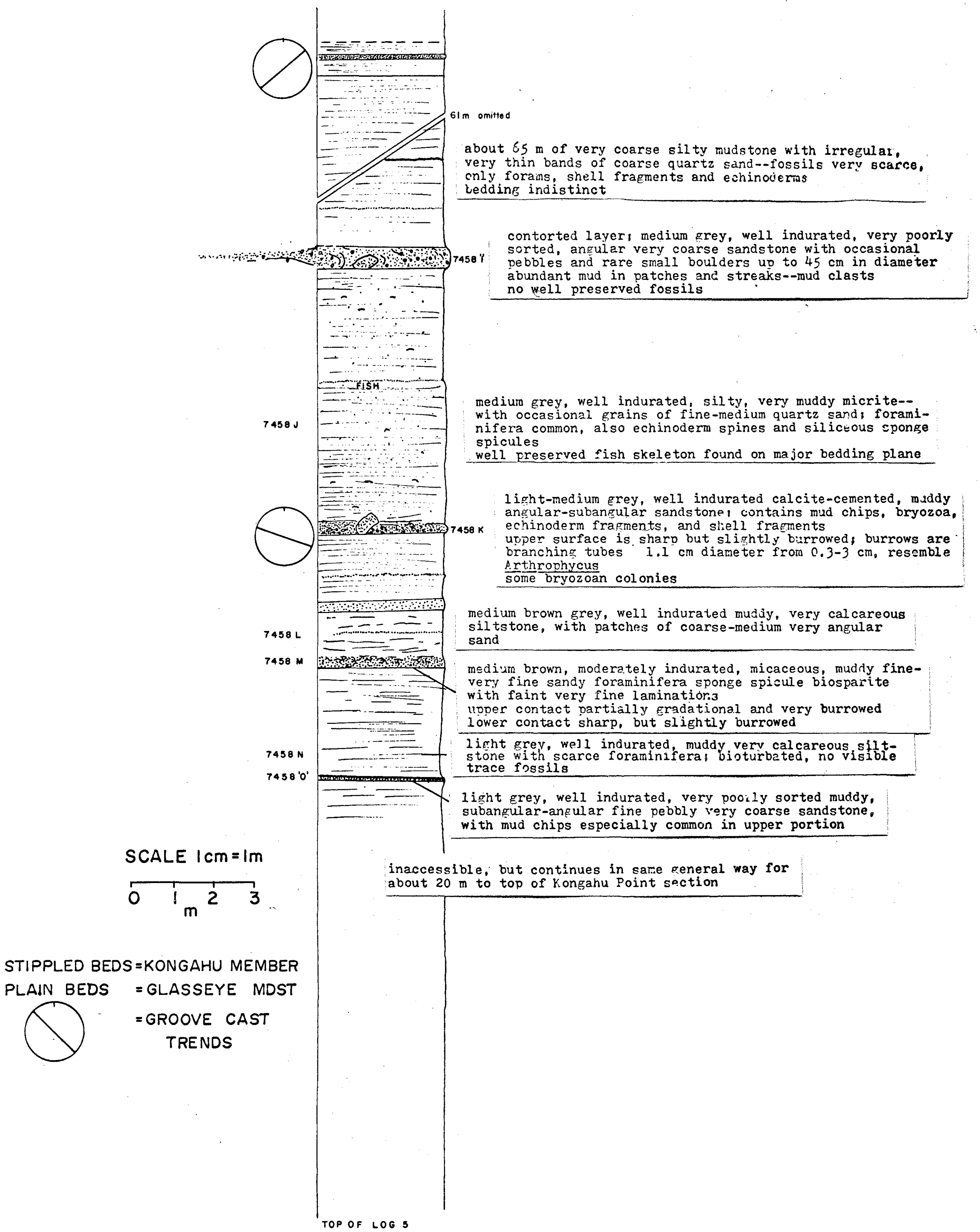


LOG 4 LIMESTONE CREEK S18/658218

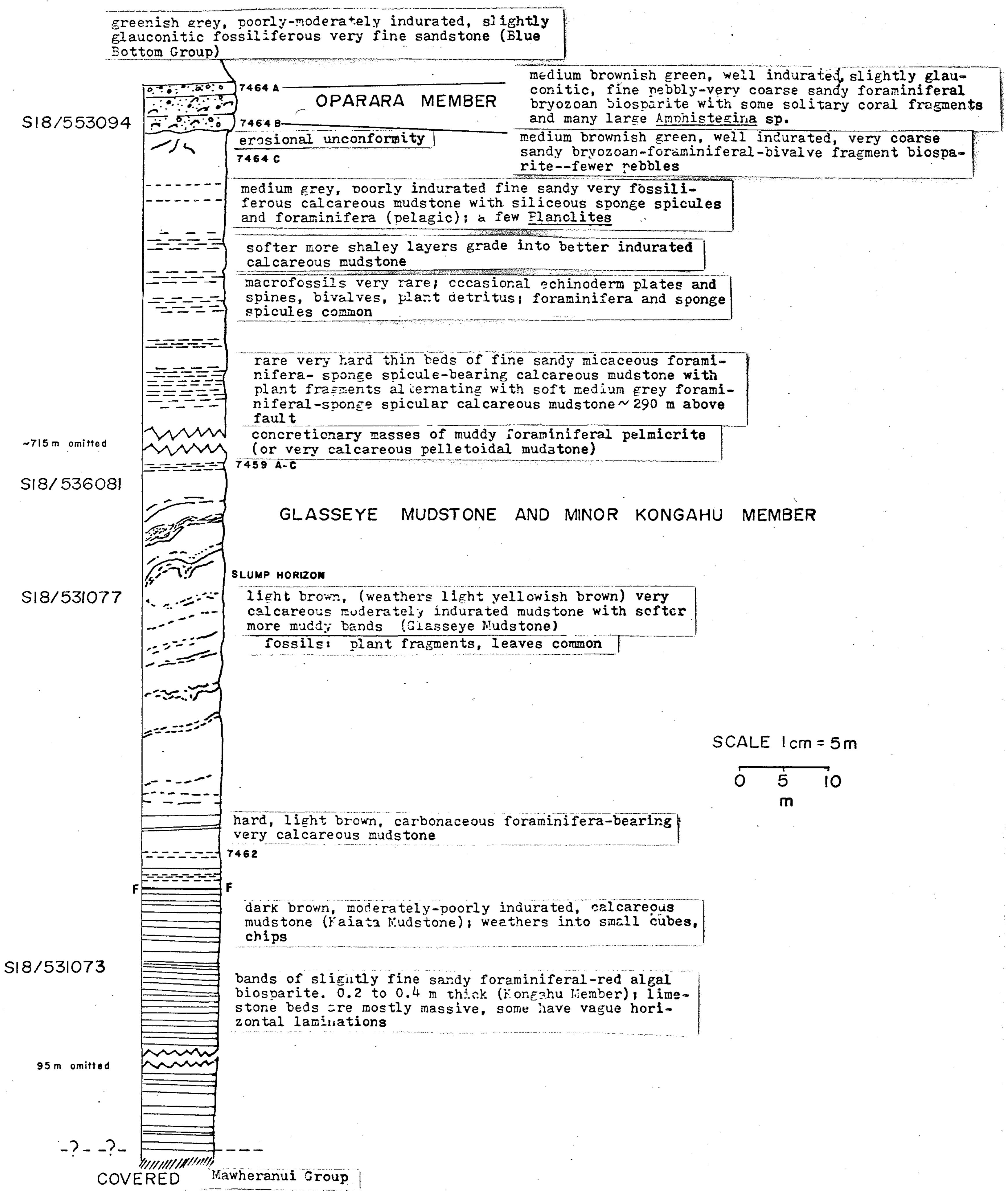


from Wellman (unpubl.); Wellman, et al., 1973; personal notes

LOG 6 MOUTH OF FALLS CREEK TO OTAHU HILL S18/485141 to 481137



LOG 9 HAPPY VALLEY SADDLE TO CORBYVALE S18/553094–531073



LOG 10 SECTION ALONG HWY 67 FROM VIEW HILL SADDLE TO MOKIHINUI RIVER S18/477012 to 424002